

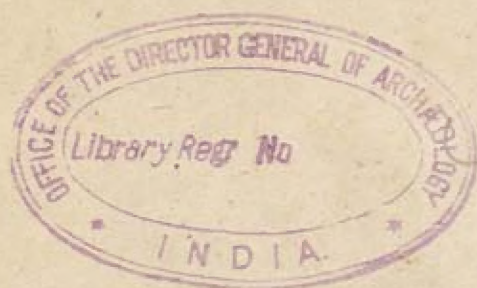
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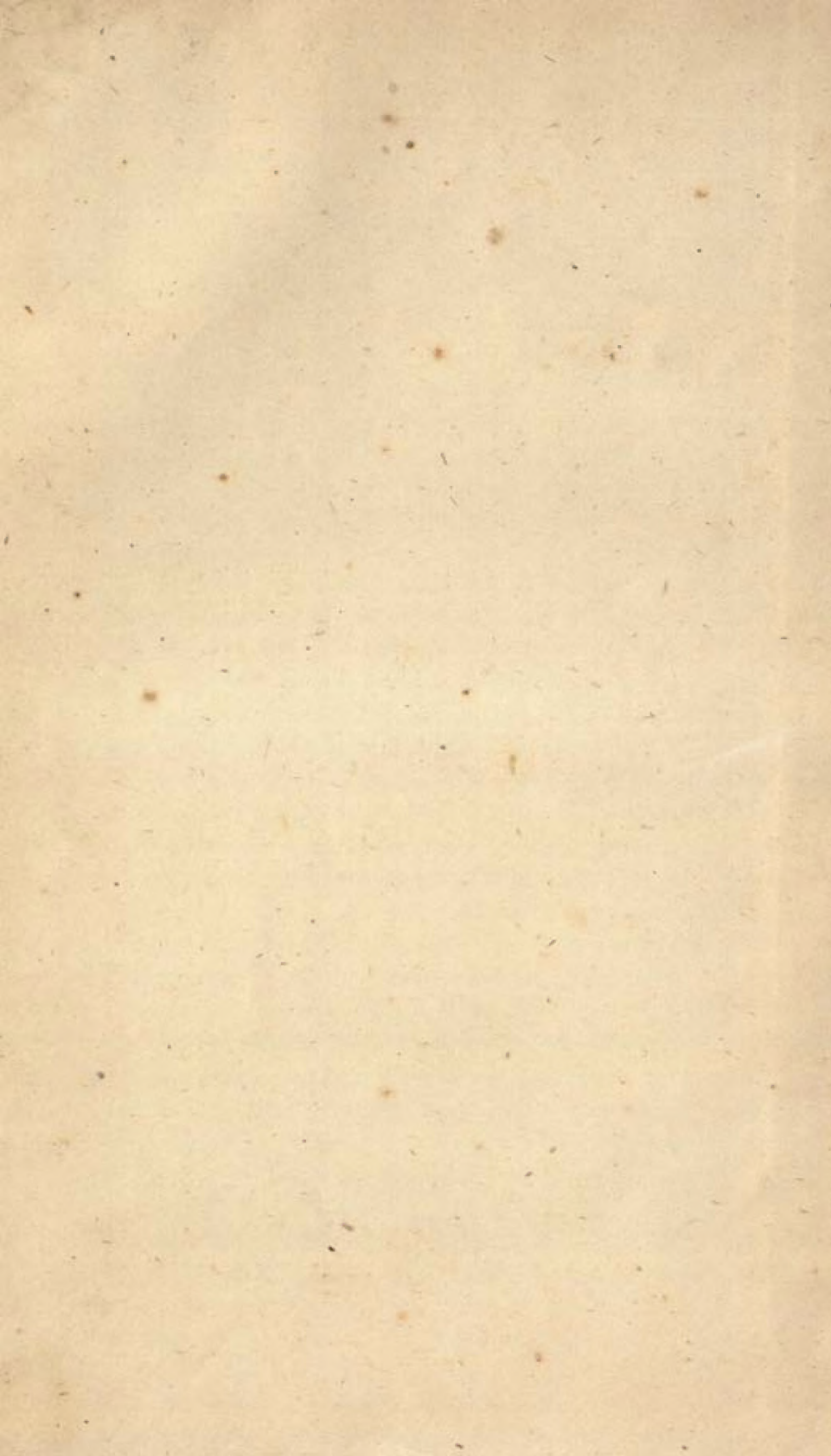
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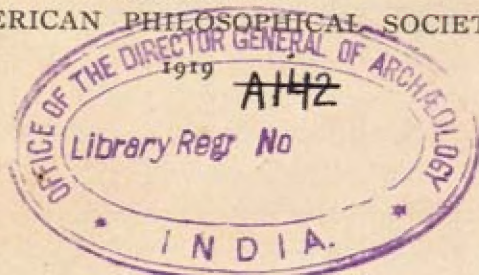
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THE PARASITIC ACULEATA, A STUDY IN EVOLUTION.<sup>1</sup>

By WILLIAM MORTON WHEELER.

*(Read April 25, 1919.)*

There is undoubtedly much to be said in favor of the opinion commonly held by entomologists that the fruitfulness of their investigations is apt to be directly proportional to the intensity of their specialization, but it is also true that this very specialization may often preclude an adequate appreciation or even a recognition of phenomena that would profoundly impress the worker who possesses more general biological interests. This statement is not inapplicable to the subject of the following study, which is an attempt to collate the data accumulated in their respective fields by a number of observers of ants, bees and wasps and relating to certain types of parasitism which keep recurring in various natural families of the Aculeata in response to frequently recurring stimuli or situations in the organic environment. The few who have published comprehensive accounts of the phenomena have failed to present them as clearly and cogently as the facts would seem to warrant. I am aware that my own treatment of the subject may leave much to be desired and especially that my account of the bees, a difficult and extensive group to which I have been able to devote comparatively little study, is rather summary, but every attempt to attain

<sup>1</sup> Contributions from the Entomological Laboratory of the Bussey Institution, Harvard University. No. 155.



broader generalization has its attendant risks and inadequacies. If I succeed in directing renewed attention to an interesting series of facts and to some of the problems which they suggest, the purpose of this article will have been accomplished.

In considering the parasitic Aculeata I shall adhere to the following classification, which though in certain respects artificial and unsatisfactory from the standpoint of phylogenetic development, will nevertheless facilitate an understanding of the history of our knowledge of the subject:

I. Nonsocial Parasites.

1. Solitary Bees.
2. Solitary Wasps.

II. Social Parasites.

1. Ants.
  - a. Guest Ants.
  - b. Slave-makers.
  - c. Temporary Social Parasites.
  - d. Permanent Social Parasites.
2. Social Bees.
3. Social Wasps.

The solitary bees may justly claim our attention first, because they comprise such a large number of parasitic forms which have been objects of study for more than a century. The taxonomy of the bees, however, notwithstanding the number of able investigators they have attracted, is still in a very unsatisfactory state. The very numerous species are often distinguishable only by very minute or dubious characters, so that many of the genera are large, homogeneous and widely distributed. Even the generic characters are often very feeble as compared with those employed by taxonomists in other Aculeate families. Hence also the higher groups, such as the tribes and subfamilies are so poorly characterized that no two melittologists agree on their limits or number. The wing venation is extraordinarily uniform throughout the whole family and the taxonomic use of the mouthparts encounters the usual difficulties which beset the employment of delicately adaptive structures. All the members of the group are of comparatively recent phylogenetic development and very highly specialized in adaptation to the



pollenation of flowering plants, themselves a group of organisms of recent origin. As manifold morphological expressions of this adaptation attention has often been called to the peculiar modification of the mouthparts for extracting nectar from flowers, the singular branched hairs of the body and modification of the hind legs or hairs on the venter in the female for carrying pollen, and the highly developed visual and olfactory organs.

On the side of the instincts there are, further, the marvelous habits of nidification which have aroused the admiration of all students since the days of Réaumur. Still the general activities of the female bee—the male is, of course, an ethological nonentity as in other Aculeates—are strangely uniform in their general outlines:—the visiting of flowers, mating, nidification, provisioning the nest with pollen and honey, oviposition. But different species visit different flowers and build their nests in different places and of different materials. All this is true of perhaps 80 per cent. of the thousands of species, but a considerable number—between 15 and 20 per cent., representing fully 70 genera—have become parasitic and have therefore ceased to collect pollen and nectar or to construct and provision nests, but instead seek out the nests of other bees and oviposit in their cells, with the result that the larvæ reach maturity by devouring the provisions so carefully stored for their own offspring by more industrious mothers.

This peculiar habit has profoundly modified the structure of the parasites. Their mouthparts have not been affected to any extent because these bees still visit flowers assiduously for food, but the collecting apparatus has atrophied and the hairs on the body and appendages have been completely or almost completely lost, so that the species have sometimes been placed in a group by themselves called *Denudatæ*. Other peculiarities are also manifested. The loss of the collecting apparatus, which is one of the most striking secondary sexual characters of the female bee, excepting in the *Prosopidinae*, which swallow the pollen instead of collecting it on their hind legs or venter, has brought about a close resemblance of the sexes to one another. In a few cases the female has even taken on a male secondary sexual character, as in the genus *Androgynella*, recently described by Cockerell (1918). It comprises two species,



*detersa* of Australia and *subrixator* of the Philippines. In both species the female, though possessing a well-developed sting, has 13-jointed antennæ, a number peculiar to the male in all other bees and in fact in most other Aculeates. The specimens cannot be gynandromorphs, because R. E. Turner found the 13 joints in 14 females of *detersa*, so that Cockerell is justified in regarding it as "certain that this is a normal condition and must represent an early stage in the evolution of a parasitic species, like those of *Calioxys* and *Stelis*. From the standpoint of genetics, it is an extraordinary case, since the female seems to have dropped her secondary sexual characters and thereby assumed those of the male which were present in her genetic constitution." He adds that "presumably the male of *A. subrixator* cannot be distinguished from *Megachile subrixator*," which is a common species in the Philippines and in all probability the host.

Another peculiarity of the parasitic bees, to which Friese has called attention, is their often very vivid coloration. Many of the species are more or less red or yellow (*Sphecodes*, *Nomada*, *Epeolus*, etc.) or banded and spotted with patches of white or blue appressed hairs or scales (*Epeolus*, *Crocisa*, *Melecta*, etc.), or are brilliantly metallic (*Exærete*, *Aglaë*). The red color suggests that of certain myrmecophilous beetles (*Lomechusa*, *Heterius*, *Claviger*, etc.) and may have a similar meaning, but it is difficult to account for the spots and bands unless we assume that they are an expression of peculiarities of metabolism, associated with the active habits of the parasites, an interpretation which has also been suggested to account for the more vivid color patterns of the males as contrasted with the conspecific females of many animals. Perhaps the peculiar odors of certain parasitic bees, *e. g.*, of *Nomada*, odors which in some cases at least seem to play a rôle in the relations to the host, also point to such peculiarities in metabolism.

From an examination of the brains of two genera of parasitic bees, *Nomada* and *Psithyrus*, von Alten (1910) concluded that their fungiform bodies, supposed to be the seat of intelligence and therefore to correspond to our cerebral hemispheres, were more feebly developed than in the nonparasitic species. He even found that the fungiform bodies of the male parasites were relatively

larger than in the females. It can hardly be claimed, however, that the parasitic bee is psychically less endowed than its host, because the finding and entering of the latter's nest presupposes instinctive activities of a high order.

Our knowledge of the habits of parasitic bees is rather meager when compared with our knowledge of the species as taxonomic units. They occur in all parts of the world, but even the hosts of many of the genera, especially of the nonholarctic forms, have not yet been ascertained. Within recent years, however, Verhoeff (1892), Höppner (1904), and Graenicher (1905) have made some careful observations on the behavior of a few European and North American species. Verhoeff studied the activities of the *Stelis minuta* larva in the nests of *Osmia leucomelana* which are in hollow blackberry stems. The *Osmia* makes a row of cells in the cavity, separating them with partitions of chewed up leaves, provisions each cell with a ball of honey-soaked pollen, the so-called "bee-bread," and lays an egg on it before closing the cell and starting another. Graenicher summarizes Verhoeff's observations in the following words:

"1. *Stelis minuta* deposits its egg earlier than the host-bee, and in the lower region of the bee-bread. 2. The larva of the parasite hatches a little earlier than that of the host-bee, whose egg is situated on top of the bee-bread. 3. Both larvæ, which at the beginning are of about the same size, partake of the bee-bread, the host-larva on top, the parasite below. 4. The latter gradually increases in size, and consequently advances towards the host-larva on top. 5. Finally the parasite, which in the meanwhile has become twice as large as the host-larva, comes in contact with the latter, kills it and eats it. Verhoeff informs us that there was a mutual exchange of hostilities between the two larvæ, each trying to grab the other with its mandibles, but that finally the parasite succeeded in burying its mandibles in the head of the host-larva. The latter was eaten up within 1 or 2 days."

Höppner's observations on the larva of *Stelis ornatula* in the cells of *Osmia parvula* and *leucomelana* agree essentially with Verhoeff's, except that he saw no struggle between the parasitic and host larva. The former bored its way upwards through the bee-bread, sought out the *Osmia* larva as soon as possible and plunged its mandibles into the body of the latter without meeting with any resistance. Like Verhoeff he found the parasitic to be larger than the host larva.



Graenicher's observations are more extensive. He studied in Wisconsin the parasitism of *Stelis 6-maculata* on *Alcidamia producta*, of *Calioxys lucrosa* on *Megachile addenda* and of *Triepeolus helianthi* on *Melissodes trinodis*. In all these cases the general behavior of the parasite is very similar to that of *Stelis minuta* and *ornatula*, but he found that the just-hatched larva has sharp, falcate jaws, which are very large in *Calioxys* and *Triepeolus* and are replaced by smaller jaws with the next moult, after it has killed the host larva. The first stage *Triepeolus* larva, moreover, has peculiar leg-like appendages which enable it to crawl about in the cell. We are justified, therefore, in speaking of a hypermetamorphosis in these bees, comparable to that of so many other parasitic insects (Rhipiphoridae, Strepsiptera, Meloidae, Eucharine Chalcididae, Chrysididae, Mantispidae, etc.). I quote a portion of Graenicher's account relating to the *Stelis* larva.

"July 9, 1903. Nest collected at Milwaukee contains 4 cells. Third cell (from below) with a parasite. On top of the bee-bread an *Alcidamia* larva, about 3 days old. On the side of the bee-bread, about half way up a *Stelis* larva feeding on bee-bread. It is smaller than the host larva, and its head is directed upward, and toward the posterior end of the latter's body.

"July 13. The parasitic larva has grown considerably but is not as large as the host larva. At 1 P.M. the parasite moves upward a short distance, comes in contact with the host larva, and secures a hold on the latter's side behind the middle of the body. The victim at first makes an effort to free itself, but offers no serious resistance. The parasite remains in the same position the whole forenoon, sucking the liquid contents of the host's body. The latter gradually perishes and shrivels.

"July 14. The parasite has released its hold on the dead host larva, and is feeding on bee-bread. It has lately increased very much in size. From now on the parasite does not pay any more attention to the remains of the host.

"In the cell just considered a single parasite was present, but in a nest collected at Milwaukee, July 15, 1903, a cell was come across with 3 parasitic larvae, all of them on the same side of the bee-bread as the head of the host larva. One of them was sitting above the middle, not far below the host larva, the second was lower down and directed laterally, and the third was below the second and quite close to it. In the evening the third parasite, which throughout the day (July 15) had been partaking of bee-bread and growing in length, reached the second and killed it. Four days later this same parasite killed the uppermost one and fed on its contents. Two days after this (July 21), the surviving parasite killed the host larva. Both were about equal in size."

These very similar observations of Verhoeff, Höppner and Graenicher on three very different genera of parasitic bees cast some doubt on the older and more meager observations which led Schmiedeknecht and Sharp to assume that the parasitic bee larva is merely a commensal that feeds so voraciously and grows so fast that it compels the host larva to perish from starvation. It was this assumption which led the earlier writers to call the parasites "cuckoo bees." It is possible, of course, that some parasites, *e. g.*, *Nomada*, which infests the nests of *Andrena* and *Halictus*, may conform to this older view, but renewed investigation is certainly demanded by the results of the authors I have been considering.

Graenicher (1906) has also made some valuable observations which show that vision as well as odor is an important factor in the parasitic bee's method of locating the nest of the host. Speaking of *Argyroselenis minima*, which is a parasite of *Colletes eulophi*, he says:

"It is quite evident that after having discovered the nest this parasitic bee pursued a course similar to that of a host-bee when constructing a nest. It started out to make a careful and repeated inspection of the environment of the nest, gradually covering more territory in different directions, but often returning to the nest as the main object of its attention. Being possessed of a good memory for visual impressions it became acquainted with the locality within 6 minutes, and experienced no difficulty in refinding the nest at its next visit after an absence of 14 minutes. It gradually acquired a thorough familiarity with the topography of the region, and on its return to the nest it was seen to fly towards the opening as directly as the owner itself.

"Such a parasitic bee when hunting for a nest of a host-bee is not always flying around in a haphazard way, trusting to its good luck in finding a nest here today, and one somewhere else tomorrow. When it has come across a suitable one it is very careful to keep this under observation, and in making its trips to and away from the nest it is directed by its visual memory in exactly the same manner as the host-bee itself. It would not be in the interest of such a bee to pursue a different course. The work of the host-bee in constructing a cell, and provisioning it with the food-supply must have progressed to a certain point before the parasitic bee may find it suitable for the reception of the latter's egg. For this reason such a bee has to make repeated visits to the nest, in order to be on hand when the right time comes. If it were in the habit of wandering around until it happened to come across a host-bee's cell in the proper stage of construction, then it might not get much chance to deposit an egg within its life-time of a few weeks duration, especially in rainy seasons. It is even possible that a parasitic bee has more than one nest under observation during the same period."



Graenicher found the behavior of the female *Triepeolus*, *Colioxys* and *Stelis* to be very similar to that of *Argyroselenis*.

There is one genus of bees, *Sphecodes*, which must be briefly considered, because it has been the center of a prolonged controversy. These insects are fairly common in Europe and North America and closely resemble the species of *Halictus* except in color, as they have the abdomen wholly or in part vivid red and in the hind tibiae which are very sparsely pilose and therefore suggest a degenerate condition of the pollen-collecting apparatus. More than a century ago de Walkenaer (1817) maintained that *Sphecodes* is a parasite of *Halictus*, and the same view was more or less emphatically maintained by Wesmael (1835), Lepeletier (1841) Spinola (1851), and Taschenberg (1866), but Fred. Smith (1851) and Sichel (1865) held that it nests independently. The controversy continued, however. Perkins (1887, 1889) believed that *Sphecodes* might be occasionally parasitic and Friese and von Buttel-Reepen (1903) regarded it as perhaps incipiently parasitic. Rudow (1902) repeated the old statement that it nests independently. Marchal (1890, 1894) and Ferton (1890, 1898) witnessed some serious combats between *Sphecodes* and the *Halicti*, whose nests it was trying to enter. Ferton (1905) saw a *Sphecodes subquadratus* breaking into the nest of *Halictus malachurus*.

"Not being able to seize by the head the sentinel bee which barred her passage, she tunneled towards the *Halictus* burrow and succeeded thus in seizing and killing the guardian, which she tossed backward out of the burrow. A second and a third *Halictus* that rose in the burrow in succession to replace the first, met the same fate."

Morice (1901) contended that such aggressive behavior showed that the *Halictus* was not a parasite, because some parasitic bees, e. g., *Nomada*, seem to entertain friendly relations with their hosts. Three investigators, however, have succeeded in breeding *Sphecodes* from *Halictus* and *Andrena* nests. Breitenbach (1878) long ago took *S. rubicundus* from the brood-cells of *Halictus 4-cinctus* and Sladen (1895) found pupæ of the same species in the nests of *Andrena nigroaenea* and *labialis*. Finally Nielsen (1903) gave cogent reasons for regarding *S. gibbus* as a parasite of *Halictus 4-cinctus*. He says:

"When quickly unearthing a nest which I had seen *Sphecodes* entering, I discovered it sitting in a cell nearly filled with honey. Later on I found several cells containing larvæ differing from those of *Halictus* and which can hardly be other than those of *Sphecodes*. Finally I found in the autumn a cell containing a dead specimen of a fully colored *Sphecodes* pupa. It is therefore proof that *Sphecodes* is a cuckoo with *Halictus*."

Nielsen calls attention to the fact that the parasitic habit of *Sphecodes* explains the great variations in size, puncturation, etc., which have led taxonomists to multiply species in the genus. He found that poorly nourished individuals are often only half the size of well-fed specimens. Perkins had previously noticed that small forms of *Sphecodes* live with small *Halicti* and *vice versâ*. Sichel, after studying 3,200 specimens of European *Sphecodes*, decided that they represented only three species. He sent 600 other specimens which he referred to two species to Foerster, who claimed that he could distinguish some 150 species among them, but wisely refrained from publishing descriptions. Similar variations are, of course, frequent in other parasitic insects, notably in Mutillidæ and in *Ceropales*.

The aggressive behavior of the female *Sphecodes*, which was also observed by Nielsen, suggests that she may enter *Halictus* cells which are already completed and destroy the egg of the host, so that her own progeny will not have to compete with the lawful owner of the bee-bread, as in the case of *Stelis* and the other parasites studied by Graenicher. At any rate our knowledge of the behavior of *Sphecodes* is in need of further careful investigation.

When commenting on the difficulties encountered by the taxonomic student of the bees, I omitted one of the greatest, viz., that presented by the numerous parasitic genera. In many cases these are known to be very closely related to the genera of their hosts, a fact which was noticed even by the early investigators, although its full significance became apparent only in the course of time, with the constant discovery of new species and genera in all parts of the world and with changes in the interpretation of general biological phenomena. The whole matter is so interesting that I may be pardoned for introducing some historical considerations.

The more than a century devoted by entomologists to the study of bees may be conveniently divided into a pre- and a post-



Darwinian period. Latreille, in a short paper, published in 1802 at the end of his remarkable volume on the habits of ants, and Kirby in the same year were the first to construct noteworthy classifications of bees. There was a remarkable agreement in their point of view, both dividing the family into short-tongued and long-tongued forms, subsequently called Andrenidæ and Apidæ, the Andrenatæ and Apiaries of Latreille and the supergenera *Melitta* and *Apis* of Kirby. The parasitic bees that were known in his day were intercalated by Latreille among the Apiaries in close proximity to their host genera. Lepeletier de St. Fargeau (1825) divided the bees into two groups, the "récoltantes," or collecting, and the "parasites," and subdivided the former according to the differences in their pollen-collecting apparatus. The views of Latreille and Lepeletier have dominated the classification of bees down to the present time. Certain German melittologists, notably Schmiedeknecht and Friese, have followed Lepeletier's scheme, whereas Westwood (1840) and most subsequent workers have agreed with Latreille. As Westwood's reasons are still interesting and include a good statement of the pre-Darwinian or special creation conception of the relations of the parasite to the host, I quote some of his remarks:

"Indeed it is to be observed that the variation in the structure of the species, thus varying in their habits, does not seem to warrant the establishment of them into separate families. This circumstance appears naturally dependent upon two considerations: 1st, it is essential that the parasite in its perfect state should possess a certain resemblance to the animal in the nest of which it deposits its eggs, so as to deceive the latter and its associates (Kirby in a footnote here calls attention to the resemblance of the Dipteron *Volucella* to *Bombus*); and 2d, the nature of the food of both being similar, the variation in structure is much less striking than if the parasite were carnivorous, as the Ichneumonidæ, and the animal attacked (as the caterpillars of Lepidoptera, etc.) herbivorous. The parasitic connection indeed goes no further than this, viz., that the larva of the parasite eats up the food of its fosterer, and so starves it to death; the larvæ of both are therefore pollenivorous, and the differences which will naturally be most striking, will consequently be found in those organs which are employed in the construction and provisioning of the nest of the working species, and which one may therefore expect to find in a less developed state than in those species which, from being parasitic, do not require their full development. Hence it is that we find the general structure of the parasitic bee closely resembling that of the bee, at the expense of whose young its own are destined to be

nourished; and hence, if we regard *Bombus* and *Psithyrus* of St. Fargeau, *Agloë* and *Englossa*, *Melecta* and *Anthophora*, or *Sphecodes* and *Halictus*, with reference to their general structure, they will be found most intimately allied; whilst if, on the other hand, we regard such portion of their economy as is connected with the formation and provisioning of their nests, it will be requisite to place them in different divisions. If we observe, however, the great variation existing among bees in this portion of their economy, it is evident that this cannot be regarded as a normal or typical character and that a distribution founded thereupon would necessarily be unnatural."

The publication of the "Origin of Species" could not fail to have its effect on the students of bees. In the light of evolution the parasitic species acquired a new meaning, for it was at once apparent that their resemblance to their hosts might have a genetic significance. One of the first to fall under the spell of the new conception was Hermann Müller (1871). He believed that the genus *Psithyrus* was of rather recent descent from its host genus *Bombus*, that *Melecta* and *Crocisa* were less recently descended from *Anthophora*, and that the phylogenetic origin of *Stelis*, *Calioxys*, *Epeolus* and *Nomada* was still more remote, although the derivation of *Stelis* and *Calioxys* from gastrilegid genera seemed clear. He was guided to these conclusions by a study of the antennæ. Referring to a table of the genera of bees he says: "An examination of this table shows that in all nonparasitic bees, without exception, the males have a shorter scape but a longer flagellum than the females, but that in some pronounced cuckoo-bees the very reverse is the case." Smell not only guides the males to the females, but also the parasites to their hosts and hence the olfactory organs of the female parasites must be highly developed. "A glance at the development of the male and female olfactory organs of the cuckoo-bees clearly supports the conclusion that in the antennæ of the females the adaptations for working in the brood-chambers have been lost *pari passu* with an increase in the olfactory organs and that these developments correspond in degree to the period of time at which the transition to a parasitic life took place." I am not aware that any study of the antennæ and their sense-organs has since been undertaken with a view to testing the correctness of Müller's conclusions. Allusion has already been made to Graenicher's discovery that the vision of the parasitic bees is an important factor in locating the nests of the host.



In 1883 Pérez published an important study of the parasitic bees and republished his general conclusions in a separate article in 1884. After careful morphological investigation he concluded that the parasitic genera must have evolved from the host genera and was able in a few instances to point out the very species from which the parasitic genus had originated. He recognized four distinct lines of development from as many host genera: *Psithyrus* from *Bombus*, *Stelis* from *Anthidium*, *Calioxys* and *Dioxys* from *Megachile* and *Sphecodes* from *Halictus*. The series of genera known as the Nomadiniæ and comprising *Epeolus*, *Melecta*, *Crocisa*, *Ammobates*, *Pasites*, *Phileremus*, *Biastes* and *Nomada*, he derived from *Calioxys* on the supposition that this genus had given rise to a whole series of parasitic forms which had acquired new hosts among the various genera of recoltant bees. He contended that Latreille's example in placing the parasitic genera next to their host genera should be followed in any attempt at a natural classification of the Apidæ. The truth of his contention has since been conceded and is clearly expressed in the classifications of Ashmead (1899), Robertson (1899) and Cockerell (1910). Dalla Torre (1896) and Friese in his work on the African bees (1909), however, adopt a compromise between the views of Latreille and Lepeletier, dividing the bees into podilegid, gastrilegid and social sections and appending to each a series of parasitic genera. Of the classifications I have seen Robertson's seems to be the most natural, but he is dealing with a limited fauna, in which the relations of the parasitic genera are few and fairly well known, whereas Dalla Torre and Friese, in an attempt to deal with the bees of remote regions or of the whole world and with dozens of imperfectly known parasitic genera, have some justification for the course they adopt. It is evident, nevertheless, that no satisfactory classification can be constructed till the precise affinities of all the parasitic genera to one another and to the host genera have been thoroughly elucidated.

The phylogenetic relationships even among the European and North American parasitic bees are still in part very problematical. Probably all agree that *Psithyrus* must be derived from *Bombus*, *Stelis* from *Anthidium* (*sensu lato*), and *Calioxys* from *Megachile*, or some closely related, now extinct, genus. But the origin of the

Nomadine series is by no means clear. Friese in his earlier work (1889) could not decide whether it was to be derived from *Calioxys*, as Pérez suggested, or from a form like *Eucera*. To-day even such an alternative seems too simple, for in all probability the long series of "Nomadine" genera now known consists of several heterophyletic groups. *Melecta* and *Epeolus* are derived from *Anthophora* by Robertson and others, and Saunders and Robertson would derive *Nomada* from *Andrena*, whereas such genera as *Ammobates*, *Blastes*, *Psites* and *Phiarus* are now supposed by Friese (1916) to be connected with *Megachile* through genera like *Cesarea* and *Paracalioxys*, the last being also the source of *Calioxys* and of *Dioxys* and *Paradioxys* through the genus *Prodiioxys*. Among the exotic parasitic genera it seems clear that some have arisen from host genera very different from those above mentioned. Thus there is every reason to suppose that *Thalestria* has arisen from *Oxae*, *Aglaë* and *Exeretæ* from *Euglossa*, *Eucondylops* from *Allodape*, *Perezia* from *Osmia*.

It will be seen, therefore, that even if we make all due allowance for dubious cases there still remain a number in which the closest morphological affinity of the parasitic is with its host genus. This is evident from the accompanying table (Table I.) in which the most clearly established cases (fully 50 per cent.) are marked with an asterisk. In constructing this table I have profited by a number of valuable suggestions kindly communicated by Professor Cockerell. We must assume, I believe, that in some cases the primitive host genera are now extinct, that in some cases, therefore, the parasites have come to infest species of genera to which they have no morphological affinity, that many parasites are directly derived from other parasitic genera and that in some cases the phenomena of parasitic convergence are so pronounced and obliterate or obscure the generic affinities to such a degree that they can be elucidated only by the most painstaking study. For my immediate purposes, however, the present results will suffice, since they agree with the conditions in other groups of Aculeata, as will be shown in the sequel.

In marked contrast with the bees, the solitary wasps comprise few parasitic species, if we exclude the Mutillidæ, which I am not



TABLE I.

## GENERA OF PARASITIC BEES.

Parasites.	Hosts.	Ancestral Genus.
* <i>Nomada</i> .....	<i>Andrena</i> , <i>Halictus</i> , <i>Eucera</i> , <i>Colletes</i> , <i>Panurgus</i> .....	<i>Andrena</i> .
* <i>Sphecodes</i> .....	<i>Halictus</i> .....	<i>Halictus</i> .
* <i>Parhalictus</i> .....	(?) <i>Halictus</i> .....	<i>Halictus</i> .
* <i>Chlerogas</i> .....	(?) <i>Thrinchostoma</i> .....	<i>Thrinchostoma</i> .
* <i>Melecta</i> .....	<i>Anthophora</i> .....	<i>Anthophora</i> .
* <i>Bombomelecta</i> .....	(?) <i>Anthophora</i> .....	<i>Anthophora</i> .
* <i>Ericrocis</i> .....	(?) <i>Anthophora</i> .....	<i>Anthophora</i> .
* <i>Crocisa</i> .....	<i>Anthophora</i> .....	<i>Anthophora</i> .
* <i>Protomelissa</i> .....	(?) <i>Anthophora</i> .....	<i>Anthophora</i> .
* <i>Melissa</i> .....	(?) <i>Anthophora</i> .....	<i>Anthophora</i> .
<i>Epeolus</i> .....	<i>Colletes</i> .....	<i>Anthophora</i> .
<i>Triepeolus</i> .....	<i>Melissodes</i> , <i>Tetralonia</i> .....	<i>Epeolus</i> .
<i>Argyroselenis</i> .....	<i>Colletes</i> .....	<i>Epeolus</i> .
* <i>Epeoloides</i> .....	<i>Macropis</i> .....	<i>Macropis</i> .
* <i>Leiopodus</i> .....	<i>Melitoma</i> .....	<i>Melitoma</i> .
<i>Osiris</i> .....	(?) <i>Tetrapedia</i> .....	<i>Tetrapedia</i> .
<i>Rhathymus</i> .....	(?) <i>Epicharis</i> .....	<i>Epicharis</i> .
<i>Mesochaira</i> .....	(?) <i>Centris</i> .....	<i>Crocisa</i> .
<i>Acanthopus</i> .....	<i>Centris</i> .....	(?) <i>Centris</i> .
<i>Eurytus</i> .....	<i>Centris</i> .....	(?) <i>Centris</i> .
<i>Mesonychium</i> .....	<i>Melitoma</i> .....	<i>Acanthopus</i> .
* <i>Aglaë</i> .....	<i>Euglossa</i> .....	<i>Euglossa</i> .
* <i>Exaerete</i> .....	<i>Euglossa</i> .....	<i>Euglossa</i> .
* <i>Perezia</i> .....	<i>Osmia</i> .....	<i>Osmia</i> .
* <i>Eucondylops</i> .....	<i>Allodape</i> .....	<i>Allodape</i> .
* <i>Stelis</i> .....	<i>Anthidium</i> , <i>Chalicodoma</i> , <i>Heriades</i> , <i>Osmia</i> , <i>Ceralina</i> , <i>Alcidamia</i> , <i>Chilos-</i> <i>toma</i> .....	<i>Anthidium</i> .
<i>Parevapis</i> .....	<i>Megachile</i> .....	<i>Stelis</i> .
<i>Euaspis</i> .....	<i>Megachile</i> .....	<i>Stelis</i> .
* <i>Thalestria</i> .....	<i>Oxæa</i> .....	<i>Oxæa</i> .
* <i>Androgynella</i> .....	<i>Megachile</i> .....	<i>Megachile</i> .
* <i>Carlxyys</i> .....	<i>Megachile</i> , (?) <i>Anthophora</i> .....	<i>Megachile</i> .
<i>Dioxys</i> .....	<i>Osmia</i> , <i>Chalicodoma</i> .....	<i>Megachile</i> .
<i>Pasites</i> .....	<i>Nomia</i> , <i>Camptopærum</i> .....	<i>Ammobates</i> .
<i>Ammobates</i> .....	<i>Anthophora</i> , <i>Macrocera</i> , <i>Saropoda</i> .....	<i>Casarea</i> .
<i>Biastes</i> .....	<i>Systropha</i> .....	<i>Ammobates</i> .
<i>Phiarus</i> .....	<i>Meliturga</i> .....	<i>Ammobates</i> .
<i>Holcopasites</i> .....	(?) <i>Calliopsis</i> .....	<i>Ammobates</i> .
<i>Oreopasites</i> .....	<i>Spinoliella</i> .....	<i>Ammobates</i> .
<i>Phileremus</i> .....	<i>Rhophites</i> , <i>Halictoides</i> .....	<i>Pasites</i> .
<i>Herbstiella</i> .....	(?) <i>Psanythia</i> .....	<i>Pasites</i> .
* <i>Psithyrus</i> .....	<i>Bombus</i> .....	<i>Bombus</i> .

including in my survey. The following are the only cases I have found in the literature. According to Ferton (1901) the Gorytid *Nysson dimidiatus* is a parasite of *Gorytes elegans*. The latter digs its burrow in the sand and provisions it with larval and adult Hemiptera; the *Nysson* finds it and often enters it during the absence of the *Gorytes*. If the latter happens to be at home the *Nysson* waits motionless about a dozen centimeters away, with its head turned towards the nest, till the *Gorytes* departs. Adlerz (1910) observed very similar behavior on the part of *Nysson maculatus* towards *Gorytes lunatus*. Apparently both species of *Nysson* destroy the *Gorytes* egg attached to the prey and lay their own in its place. In 1887, at a time when nothing was known of the parasitic habits of *Nysson*, Handlirsch called attention to the superficial resemblance of some of the species to parasitic bees.

Williams (1913) and the Raus (1918) have described an interesting sporadic case of parasitism in *Stizus uncinatus*, a wasp belonging to a very different family, the Bembicidae. The *Stizus* digs its way into the nest of a Sphecid, *Chlorion thomae*, after the latter has provisioned it with a cricket, oviposited and closed the entrance. After the Bembicid has entered the chamber it devours the *Chlorion* egg and deposits its own so that the larva can have the cricket all to itself. This case is extraordinary because the other species of *Stizus* (*S. tridens* and *errans*), whose habits have been studied by Fabre (1886) and Ferton (1899, 1908, 1910, 1911), dig their own burrows in the sand, glue their egg to the bottom of the cell and feed the hatching larva continuously with Hemiptera after the manner of other Bembicids (*Bicyrtes*). Ferton has also observed similar behavior in *S. gazagnairei* and *fertoni*. According to the same observer (1899, 1901, 1908) *S. fasciatus* feeds its young with immature crickets. Our American *Stizus* with the exception of *uncinatus*, seem to have similar habits. During the summer of 1917 I saw a flourishing colony of a small undetermined species near Tempe, Arizona. It comprised thousands of individuals, all nesting close together in the sand, like *Bembix*.

The remaining parasitic wasps belong to the family Psammocharidae (Pompilidae), all of which prey on spiders. In two of his papers (1890, 1891) Ferton has shown that some individuals of



*Pompilus rufipes* (now called *Psammochares*) have acquired the habit of robbing other individuals of their prey which they then bury and furnish with an egg. They even wage fierce battles for one another's spiders. These observations acquire added interest in connection with another very closely related species, *P. pectinipes*, which, according to Ferton (1901, 1902, 1905), enters the sealed nests of *P. rufipes*, eats its egg and deposits its own on the spider. Ferton was thus led to advance the opinion that we have in *pectinipes* a parasite that has just become detached phylogenetically from its host species.

"The parasitic habit," he says, "would therefore appear to have been built up in the following manner: *P. rufipes*, living in colonies, has acquired the habit of stealing the prey of its neighbor and even of fighting for the possession of prey not its own. Some individuals finally learned to steal the spiders that had been buried, either by driving away the rightful owner while she was sealing her burrow, or by ferreting through the soil occupied by the colony in search of sealed burrows. Their descendants, inheriting this habit, gave up constructing a nest and transporting the stolen prey to it and left it in the cell where it was discovered, simply substituting their egg for the one it bore. Thus *P. pectinipes* was evolved, scarcely distinct from the maternal stock in many of its anatomical characters but become a parasite on the species from which it arose."

In Sweden Adlerz (1910, 1912) found that *P. campestris* exhibits a similar parasitism on *P. unguicularis* and *P. aculeatus* on *P. rufipes* and *fumipennis*, and Ferton (1891) has shown that *P. viaticus* and *pulcher* resemble *rufipes* in their habit of appropriating the prey of other individuals of their own species.

Finally we have among the Psammocharids a distinct and peculiar genus, *Ceropales*, all the species of which are parasites on other genera of the family. Lepeletier (1827) was the first to regard *Ceropales* as a parasite, but Walsh was the first to breed it from the nest of another Psammocharid. Riley and Walsh (1869), in their paper on wasps and their habits, state that a male *Ceropales*, which they described under the name *C. rufiventris*, but which is now known as *C. robinsoni* Cresson, emerged from a mud cell that had been constructed and provisioned by *Agonia bombycina*. That they were fully aware of the importance of this observation is clear from the following remark:

"The inference is unavoidable—more especially as we had previously bred very numerous specimens of the same little mud-dauber from the same kind of mud-cells obtained in northern Illinois—that this gaily dressed Spider wasp (*Ceropales*) had sometime in the summer of 1867, laid an egg in one of the five mud cells found in south Illinois, and thus appropriated to the use of its future larva the supply of food laid up by the provident care of the unfortunate, dingy looking little mud-dauber for its own offspring. Otherwise it is impossible to account for two distinct kinds of wasp hatching out from the same lot of mud cells."

Pérez (1894) and Ferton (1897) made some very interesting observations in France on the behavior of *Ceropales maculata* and *cribrata*, showing that these wasps are parasitic on various species of *Psammochares* and *Aporus*, and Adlerz (1902) has succeeded in giving us a complete account of the behavior of *C. maculata* as he observed it in Sweden. This behavior is so interesting, especially in connection with Graenicher's observations on the parasitic bees, that I subjoin a translation of the German résumé of the paper:

"*Ceropales* has the habit of visiting the breeding grounds of *Pompilus* species and there alights on small eminences of the soil in order to spy on the Pompilids while they are dragging in their paralyzed spiders. The tense attitude of the wasp, her deflected antennæ and her movements as she turns towards a Pompilid that has just come within the range of her vision, are indicative of her keen interest. As Pérez and Ferton have observed, the *Ceropales* either alights on the spider while it is being borne along by the *Pompilus*, unobserved by the latter, or on a spider that is lying unguarded in the open or concealed above the ground, while its captor is busy digging her nest. In either case the *Ceropales* can be seen bending the tip of her abdomen under the spider for the evident purpose of ovipositing. Ferton saw a *Ceropales cribrata* follow a *Pompilus chalybeatus* into her burrow while she was dragging in a spider, but although a *Ceropales* larva was afterwards found on the prey, it is not certain that the egg was laid on this occasion. As will be seen from what follows, it might have been laid previously. The only time I saw a *Ceropales* enter a *Pompilus* burrow was when a *P. niger* was still busy excavating. No spider was therefore on hand and, of course, oviposition could not have occurred. It was merely a sign of impatience on the part of the parasite, which, after persistently watching the digger, stole down into the burrow as if to inspect the progress of the work. I was present also on a second exceptional occasion when a *Ceropales* pounced down with such violence on a *P. cinctellus* with its spider that the two wasps and the spider tumbled about together. The little *P. cinctellus* was so dismayed that she flew away in great haste and never returned. On this occasion the egg which the *Ceropales* probably laid during her subsequent tedious manipulation of the spider must have perished, because the spider was left in the open where it was exposed to ants and other predatory



insects. That the *Pompilus* suspects the hostile intentions of the *Ceropales* is clear from the behavior of a *P. viaticus* that hid with her spider among the dense grass-blades of a road-side and would not venture into the open because she was being watched by two female *Ceropales* each perched on a grass-blade, stretching its antennæ downward and edging nearer from time to time. The angry *Pompilus* finally gave chase to the parasites and only after they had flown away did she leave her concealment with her prey.

"When a spider on which a *Ceropales* has just alighted is examined, the egg cannot be seen at first because it is placed in such an unsuspected spot. At the base of the ventral surface of the abdomen the spider has two slit-shaped stigmata which open into the lung-books. The wasp inserts her egg into one of these. The stigmata look like pockets, with very closely fitting flaps. After the egg is in place the orifice of the pocket sometimes gapes slightly so that one end of the egg can be seen. This is apt to be the case in *Drassodes*, but in the large Lycosids the pockets are so capacious that they completely conceal the egg. The place is obviously selected because in it the egg is perfectly protected when the spider is later dragged into the burrow by its rightful owner, for it is evident that if the egg were merely attached to the surface, it would be exposed to serious injury while the spider is being drawn through the narrow burrow. The last abdominal segment of the female *Ceropales*, which is constructed like a short, flat, truncated ovipositor—a structure unique among the solitary wasps—evidently represents an adaptation to the narrow, slit-shaped stigmata, since the latter can be opened by means of such an instrument and the egg inserted. Not infrequently I have seen an egg in each of the lung-books of the same spider. Since the *Pompilus* later attaches its own egg to the side of the spider's abdomen, the situation becomes very complicated, as there are then three rival claimants for the same spider which is sufficient food for only one. A few successful breeding experiments have revealed the drama that is subsequently enacted in the dark burrow.

"After an embryonic period of two to three days, the *Ceropales* larva hatches. Its anterior portion, as far back as the tenth segment, extends straight out from the stigma, while its posterior portion remains concealed in the lung-book. Soon the exposed portion is seen to bend downward till the head touches the spider's belly and the larva begins to feed. As soon as the *Ceropales* in the other lung-book hatches the older larva evidently smells a rival, for it stops feeding, stretches itself out and moves its anterior end freely about in the air in the direction of its competitor. The latter is at first out of reach, but as soon as the older larva has fed and grown sufficiently in length it attacks its younger companion, which is quite unable to escape its fate. After its cannibal feast the *Ceropales* larva again bends down and continues to devour the spider. Not till several days have elapsed does the *Pompilus* larva hatch, although the egg was laid not more than a few hours after the *Ceropales* egg. When the *Pompilus* larva begins to grow the *Ceropales* larva becomes aware of a new rival and turns in its direction. When a little later it has grown sufficiently to reach the *Pompilus* larva, the latter's fate, too, is sealed. With the elimination of its last com-

petitor the *Ceropales* larva turns again to the spider and devours it completely except for a few unassimilable remnants. Then the larva weaves a network of pale brown threads among which on the following day it spins a pale brown cocoon. In one case which I observed the feeding period of the larva extended over a period of 12 days."

It will be seen that the general outlines of the behavior of the solitary parasitic bees and wasps are strikingly similar. Among the wasps we can recognize two types, that of *Nysson*, *Stizus uncinatus* and *Psammochares pectinipes* and that of *Ceropales*, whereas in bees only a single type, bearing a great resemblance to that of *Ceropales*, is known. It is probable, nevertheless, as I have indicated above, that the *Nysson* type may be represented among the bees by *Sphecodes*. The two types are shown in the accompanying diagrams in which the main activities of the parasite and its host are represented in parallel series.

#### *Nysson.*

*Nysson* ..... Mating ..... Finding Host Nest .....  
*Gorytes* ..... Mating ..... Nidification, Provisioning, Oviposition.  
 Destroying Host Egg ..... Ovipositing ..... Larva Appropriating Prey.  
 .....

#### *Ceropales.*

*Ceropales* ..... Mating ..... Finding Host and Prey, Ovipositing.  
*Psammochares* ..... Mating ..... Provisioning, Nidification .....  
 ..... Larva feeding ..... Killing Host Larva ..... Appropriating Prey.  
 Oviposition ..... Larva feeding .....

#### *Stelis.*

*Stelis* ..... Flower visiting ..... Mating ..... Finding Host Nest, Ovipositing.  
*Alcidamia* ..... Flower visiting ..... Mating ..... Nidification, Provisioning .....  
 ..... Larva feeding ..... Killing Host Larva ..... Appropriating Food.  
 Ovipositing ..... Larva feeding .....

In all the cases the parasite takes possession of the food-supply (prey or bee-bread) by eliminating the egg or young larva to which it belongs as a result of the activities of the host, but this elimination may be effected in two ways, either by the adult or by the larval parasite. In the *Nysson* type the mother appropriates the prey and bequeaths it to her offspring, in the *Ceropales-Stelis* type the larval



parasite seizes the prey or food for itself, or, regarding the situation merely from the standpoint of the individual life-history of the parasite, we may say that it is predacious either in its first larval stage or as an adult on the egg or young larva of the host. The host egg or larva constitutes an obstacle to the parasite's enjoyment of the prey or bee-bread, and as the parasite is a true insect bolshevik and member of the I. W. W. its life purpose is completely expressed in the impudent imperative: "Get out, I want your place." Nor is it surprising that long before the Russian soviets the parasitic wasps and bees had learned that the quickest way to remove a living obstacle is to kill it.

There is some difficulty in deciding which of the two types of parasitism represented in the diagrams is the more primitive. Probably the more aggressive *Nysson* type was the earlier as indicated by the behavior of *Psammochares rufipes* and *pectinipes*. On this supposition the rôle of assassin, directed not only against the host larva, but also against any competing larva of its own species, was acquired later by the larval parasite as a result of neglect on the part of the mother to destroy the egg of the host. The same type of behavior, however, is also seen in many other insects when more than one egg is laid by the mother in a very limited supply of food, *e. g.*, among the larval egg-parasites (Proctotrupids) and the caterpillars that live in the heads of composite flowers (Rabaud, 1912, 1914). In the larval egg-parasites the large, sickle-shaped jaws are beautifully adapted for the purpose of killing competing individuals of the same species, and the similar mandibles described by Graenicher in larval bees of the genera *Stelis*, *Calioxys* and *Triepolus* are equally useful in destroying both the competitors of the same species and the host larva.

The social parasites are most abundantly represented and have been most extensively studied among the ants. The literature on the subject is so voluminous that I am unable to deal with it here. Much of it is cited in my ant book (1910), where the subject is considered in greater detail, and in the first volume of Wasmann's "Gesellschaftsleben der Ameisen" (1915). As would be expected, the conditions become very complex when a social organism such as a colony of ants becomes parasitic on another colony. Among

the parasitic relationships four types can be recognized. One of these, corresponding to Wasmann's category of "compound colonies" is represented by a number of small species which live in little nests that communicate with the nests of the host by tenuous galleries. The two species bring up their brood separately, but the workers consort with one another freely and amicably in the galleries and chambers of the host. The relations of parasite and host, where they have been determined, are much like those exhibited between certain ants and their myrmecophiles (symphiles). The most typical of these guest ants is our North American *Leptothorax emersoni*, the behavior of which I have elsewhere described in detail. From the accompanying table (Table III.), in which all the known guest ants and their hosts are listed, it will be seen that none of the former is congeneric with its host. Emery's statement (1909), however, that: "The myrmecophilous ants are not derived from forms allied to their host species, but from other genera or even from other subfamilies," is not strictly true, though in all probability the guest-ants have developed, as he contends, from predatory thief-ants, of which quite a number of species are known to nest in the walls of the nests of termites and larger ants and to prey on their brood.

The three other types of parasitism, representing Wasmann's category of "mixed colonies," are the slave-makers, temporary and permanent social parasites, which agree in living so intimately with their host in the same nest that the two species bring up their broods in common. The differences between the three types is, however, very striking when we follow the development of the parasitic colony, although it is founded in every case by a single recently fecundated female, or queen, that succeeds in entering and establishing herself in the nest of the host species. The queen slave-maker, at least in species like *Formica sanguinea*, breaks into the host nest and appropriates and fiercely defends a portion of the host brood till it matures and surrounds her with a number of loyal workers, which are then able to rear the brood hatching from her eggs. The workers produced by such a queen have the extraordinary habit of making periodical, organized raids during the summer months on other colonies of the host species (usually *Formica*



TABLE II.  
PARASITIC WASPS.

Parasites.	Hosts.	Habitat.	Ancestral Genus.
<i>Stizus unicoloratus</i> .....	<i>Chlorion thoma</i> .....	Nearctic .....	(?) <i>Sphæcius</i> .
<i>Nysson dimidiatus</i> .....	<i>Gorytes elegans</i> .....	Paleartic .....	<i>Gorytes</i> .
<i>Nysson maculatus</i> .....	<i>Gorytes lunatus</i> .....	Paleartic .....	<i>Gorytes</i> .
<i>Psammochares pectinipes</i> .....	<i>Psammochares rufipes</i> .....	Paleartic .....	<i>Psammochares</i> .
<i>Psammochares campestris</i> .....	<i>Psammochares unguicularis</i> .....	Paleartic .....	<i>Psammochares</i> .
<i>Psammochares aculeatus</i> .....	<i>P. rufipes</i> and <i>fumipennis</i> .....	Paleartic .....	<i>Psammochares</i> .
<i>Ceropales</i> (many species) .....	<i>Psammochares</i> , <i>Agenia</i> , <i>Aporus</i> .....	Holarctic .....	<i>Agenia</i> .
<i>Vespa austriaca</i> .....	<i>V. rufa</i> and (?) <i>consobrina</i> .....	Holarctic .....	<i>Vespa</i> .
<i>Vespa arctica</i> .....	<i>Vespa diabolica</i> .....	Nearctic .....	<i>Vespa</i> .

TABLE III.

## XENOMOTIC (MYRMECOPHILOUS) PARASITES.

Parasites.	Hosts.	Habitat.	Ancestral Genus.
<i>Leptothorax emersoni</i> .....	<i>Myrmica brevinodis</i> .....	Nearctic .....	<i>Leptothorax</i> .
<i>Symmyrmica chamberlini</i> .....	<i>Myrmica (Neomyrma) mutica</i> .....	Nearctic .....	<i>Leptothorax</i> .
<i>Formicoxenus nitidulus</i> .....	<i>Formica rufa</i> and <i>pratensis</i> .....	Paleartic .....	<i>Leptothorax</i> .
<i>Formicoxenus ravoixi</i> .....	<i>Leptothorax unificatus</i> .....	Paleartic .....	<i>Leptothorax</i> .
<i>Formicoxenus corsicus</i> .....	(?) <i>Leptothorax</i> sp. ....	Paleartic .....	<i>Leptothorax</i> .
<i>Phacota nonaltheri</i> .....	<i>Monomorium subnitidum</i> .....	Paleartic .....	<i>Monomorium</i> .
<i>Phacota siceli</i> .....	(?) <i>Monomorium</i> sp. ....	Paleartic .....	<i>Monomorium</i> .

*fusca* or one of its varieties), and of carrying their larvæ and pupæ home and permitting a certain number of them to hatch as "slaves," so that the colony is maintained as an intimate mixture of two species, at least for a considerable period. The queen *Polyergus*, however, kills the queen of the host colony whose nest she enters and is adopted by the workers, and the slave-making, or dulotic raids of her offspring are even more perfectly organized than in *sanguinea*, since *Polyergus* in all its phases depends absolutely on the slaves, or host workers for its food, the rearing of its young and the construction of the common nest. It will be noticed from the table (Table IV.) that all the slave-making, or dulotic parasites belong either to the same genera as their hosts or to closely allied genera, though the latter represent two different subfamilies.

The recently fecundated queen of the temporary social parasites belonging to *Formica* species of the *rufa*, *microgyna* and *exsecta* groups, *Bothriomyrmex*, *Lasius umbratus* and *fuliginosus* or some species of *Aphanogaster*, enters the nest of the host in a conciliatory or at any rate non-aggressive manner, and after being adopted by the workers, supplants the host queen, when she is killed either by her own workers or by the parasite, which then proceeds to produce her own brood to be reared by the host workers. The offspring of the parasite, however, are not slave-makers, so that the host workers gradually die off, leaving a pure and eventually flourishing colony of the intrusive species. As shown in the table (Table V.), all the temporary social parasites belong to the same genera as their hosts, although these genera represent at least three different subfamilies.

The queen of the permanent social parasites enters the host colony in the same insinuating and conciliatory manner as the temporary social parasite and is definitively adopted in the same manner after the host queen has been eliminated, but the rate of development of the parasitic brood is very rapid, so that adult males and females are produced within the lifetimes of the host workers. This development of the sexual forms is the more accelerated because the worker caste has disappeared among the permanent social parasites, which represent the culmination, or, more properly speaking, the level of the greatest "degeneration" (specialization)



TABLE IV.  
SLAVE-MAKING, OR DULOTIC PARASITES.

Parasites.	Hosts.	Habitat.	Ancestral Genus.
<i>Strongylognathus</i> sp. ....	<i>Tetramorium caespitum</i> .....	Paleartic .....	<i>Tetramorium</i> .
<i>Harpagoxenus sublaevis</i> .....	<i>Leptothorax acervorum</i> .....	Paleartic .....	<i>Leptothorax</i> .
<i>Harpagoxenus americanus</i> .....	<i>Leptothorax curvispinosus</i> .....	Neartic .....	<i>Leptothorax</i> .
<i>Myrmoxenus gordigianii</i> .....	<i>Leptothorax servulus</i> .....	Paleartic .....	<i>Leptothorax</i> .
<i>Formica sanguinea</i> .....	<i>Formica fusca</i> .....	Paleartic .....	<i>Formica</i> .
<i>Formica sanguinea</i> subsp. ....	<i>F. fusca</i> vars. and <i>pallide-fulva</i> vars. ....	Neartic .....	<i>Formica</i> .
<i>Polyergus rufescens</i> .....	<i>Formica fusca</i> .....	Paleartic .....	<i>Formica</i> .
<i>Polyergus rufescens</i> vars. ....	<i>Formica fusca</i> and vars. ....	Neartic .....	<i>Formica</i> .
<i>Polyergus lucidus</i> .....	<i>Formica pallidefulva</i> subsp. ....	Neartic .....	<i>Formica</i> .

TABLE V.

## TEMPORARY SOCIAL PARASITES.

Parasites.	Hosts.	Habitat.	Ancestral Genus.
<i>Pseudomyrma flavidula</i> .....	<i>Pseudomyrma elongata</i> .....	Neotropical .....	<i>Pseudomyrma</i> .
<i>Aphenogaster tennesseensis</i> .....	<i>Aphenogaster fulva</i> .....	Neartic .....	<i>Aphenogaster</i> .
<i>Aphenogaster marie</i> .....	(?) <i>Aphenogaster fulva</i> .....	Neartic .....	<i>Aphenogaster</i> .
<i>Crematogaster (Atopogyne)</i> sp. ....	<i>Crematogaster</i> sp. ....	Ethiopian .....	<i>Crematogaster</i> .
<i>Crematogaster (Oxygyne)</i> sp. ....	<i>Crematogaster</i> sp. ....	Paleotropical .....	<i>Crematogaster</i> .
<i>Bothriomyrmer meridionalis</i> .....	<i>Topinoma erraticum</i> .....	Paleartic .....	<i>Topinoma</i> .
<i>Lasius (Formicina) umbratus</i> .....	<i>Lasius niger</i> .....	Paleartic .....	<i>Lasius</i> .
<i>Lasius (Formicina) subumbratus</i> .....	<i>L. niger</i> and <i>silkensis</i> .....	Neartic .....	<i>Lasius</i> .
<i>Lasius (Dendrolasius) fuliginosus</i> , ....	<i>L. (Formicina) umbratus</i> .....	Paleartic .....	<i>Lasius</i> .
<i>Formica (rufa and exsecta groups)</i> , ....	<i>Formica fusca</i> .....	Paleartic .....	<i>Formica</i> .
<i>F. (rufa, microgyna and exsecta groups)</i> , ....	<i>F. fusca</i> vars. and <i>F. pallidefulva</i> vars. ....	Neartic .....	<i>Formica</i> .

TABLE VI.

## PERMANENT SOCIAL PARASITES (ANTS WITHOUT WORKERS).

Parasites.	Hosts.	Habitat.	Ancestral Genus.
<i>Symphycidole eleccbra</i> .....	<i>Pheidole ceres</i> .....	Nearctic .....	<i>Pheidole</i> .
<i>Epipheidole inquilina</i> .....	<i>Pheidole ceres</i> .....	Nearctic .....	<i>Pheidole</i> .
<i>Parapheidole belli</i> .....	(?) <i>Pheidole</i> sp. ....	Malagasy .....	<i>Pheidole</i> .
<i>Sifolinia lawae</i> .....	(?) <i>Pheidole</i> sp. ....	Palaearctic .....	<i>Pheidole</i> .
<i>Anergatides kohli</i> .....	<i>Pheidole melancholica</i> .....	Ethiopian .....	<i>Pheidole</i> .
<i>Wheeleriella santschii</i> .....	<i>Monomorium salomonis</i> .....	Palaearctic .....	<i>Monomorium</i> .
<i>Wheeleriella adulatrix</i> .....	<i>Monomorium subnitidum</i> .....	Palaearctic .....	<i>Monomorium</i> .
<i>Wheeleriella verougtoni</i> .....	<i>Monomorium indicum</i> .....	Palaearctic .....	<i>Monomorium</i> .
<i>Epocus pergandei</i> .....	<i>Monomorium minimum</i> .....	Nearctic .....	<i>Monomorium</i> .
<i>Epixenus andrei</i> .....	<i>Monomorium venustum</i> .....	Palaearctic .....	<i>Monomorium</i> .
<i>Epixenus biroi</i> .....	<i>Monomorium creticum</i> .....	Palaearctic .....	<i>Monomorium</i> .
<i>Myrmica myrmoxena</i> .....	<i>Myrmica lobicornis</i> .....	Palaearctic .....	<i>Myrmica</i> .
<i>Hagioxenus schmitzi</i> .....	<i>Tapinoma erraticum</i> .....	Palaearctic .....	<i>Monomorium</i> .
<i>Anergatus atratulus</i> .....	<i>Tetramorium caespitum</i> .....	Palaearctic .....	(?) <i>Tetramorium</i> .



among the parasitic ants. The list of the species in the table (Table VI.) shows that they all belong to a single subfamily, the Myrmicinae, and, with the exception of *Hagioxenus*, to genera differing from though allied to their hosts.

The tables IV. to VI. are much more striking as illustrations of the natural affinities of the parasites to their respective hosts than the table of the bees (Table I.). This is undoubtedly due partly to the fact that the ant-parasites are structurally much less sharply distinguishable from their hosts and partly to the different views of myrmecologists and melittologists concerning the scope and dignity of the genus as a taxonomic category. The myrmecologist is being so constantly impressed with the great structural variations that may exist in the same colony of ants and often therefore among the offspring of the same mother, that he is apt to be a "lumper" with a vengeance, whereas the melittologist, especially on our radical and progressive American continent, seems to develop a veritable passion for erecting new genera or even subfamilies on very minute morphological characters. Thus Ashmead created a family Psithyridae and Cockerell a subfamily Psithyrinae for the bees of the single genus *Psithyrus*, although no one doubts that these insects are very closely related to *Bombus*, whereas no myrmecologist has dreamed of placing the aberrant, workerless parasite *Anergates atratulus* even in a distinct subfamily, although it differs much more profoundly from *Tetramorium* and other Myrmicine genera than *Psithyrus* from *Bombus*. No melittologist, moreover, ever thinks of placing a new parasitic bee in one of the known genera of recoltant bees, because the absence of the collecting apparatus is tacitly assumed to have decided generic or even subfamily value, but among the ants there are several genera (*Formica*, *Lasius*, *Aphanogaster*, *Crematogaster*, *Leptothorax*) which are made to include both parasitic and nonparasitic species, because there are no morphological characters by which they can be satisfactorily distinguished.<sup>2</sup>

Leaving out of consideration the guest ants, the origin of which, as we have seen, can be accounted for in the same way as the myr-

<sup>2</sup> Forel has, indeed, placed *Formica sanguinea* in a separate subgenus, *Raptiformica*, and its slave in another subgenus, *Serviformica*, but in my opinion without sufficient justification.

mecophiles, there remains the interesting problem as to the phylogenetic relations of the slave-makers, temporary and permanent social parasites. Obviously the permanent parasites can be readily conceived as developing either from temporary parasites or from dulotic species. The fact that there are among the social bees and wasps, as will be shown in the sequel, certain forms which agree in all essential particulars with the permanent social parasites among ants, although for obvious reasons they cannot have arisen from dulotic forms, would seem to point to the origin of the permanent from the temporary type of social parasitism. On the other hand, *Polyergus* seems clearly to be in a stage transitional from dulotic to permanent social parasitism, and a more advanced stage appears to be represented by *Strongylognathus testaceus* which lives with *Tetramorium caespitum* and produces workers which are few in number and endowed with very feeble slave-making proclivities.

It is more difficult to determine the phylogenetic relations of the dulotic to the temporary parasites. Wasmann (1905), Emery (1909), Viehmeyer (1909, 1911), Brun (1912) and I have discussed this matter in several papers. Wasmann holds that temporary social parasitism, which I first discovered in various North American species of *Formica*, arose from the pleometrosis of such forms as *Formica rufa*. In a single colony of this and other acervicolous species the females may be very numerous and new nests may be formed by daughter queens departing from the maternal nest with contingents of workers, or recently fecundated queens may secure adoption in other nests of their own species. At first I was inclined to derive both dulosis and temporary social parasitism from such conditions, but Wasmann insisted on deriving dulosis from temporary social parasitism, a view which Emery, Viehmeyer, Brun and I have rejected as unsound on the principle that parasitism may readily arise from predatism, but that the reverse development is biologically highly improbable. I am now inclined to agree with Emery that pleometrosis and the adoption of queen ants by workers of their own species are probably phenomena *sui generis* which did not lead to social parasitism, that we must assume a predatory stage not unlike that of *F. sanguinea* as the starting point for dulosis and that temporary social parasitism



was a subsequent development. Probably the predatory *sanguinea* queen originally entered *fusca* nests for the purpose of devouring the brood, but later came to care for the larvæ and pupæ till they hatched. We may conceive that the number of appropriated *fusca* young was more than was needed as food and that the queen acquired a fostering relation towards the remainder by coming in contact with the buccal secretions or fat-exudates of the larvæ. In other words, trophallactic relations were established between the queen and the alien brood and led to a rearing of the latter (Wheeler, 1918). This might offer a simple explanation of dulosis, a phenomenon which has always seemed unique and difficult of explanation. At any rate it furnishes an hypothesis to be tested by a closer study of the relation of *F. sanguinea* to the larval *fusca*.

Among the social bees there is only one parasitic genus, *Psithyrus*, to which I have repeatedly alluded. Kirby was the first to distinguish these bees from their hosts, the species of *Bombus*, as long ago as 1802, but a genus was first established for them by Lepeletier in 1841. The habits of *Psithyrus*, as described by Hoffer (1881, 1888), Wagner (1907) and Sladen (1912), show that it is to be regarded as a permanent social parasite. Like the ants of this type, it lacks the worker caste. The female hibernates alone like the queen *Bombus* and enters and secures adoption in a young colony of the latter, usually after the first batch of workers has emerged. The *Psithyrus* female has a tougher integument and a stouter, more curved sting than *Bombus*, and though she visits flowers, she does not collect pollen or nectar. After entering the *Bombus* nest Sladen says:

"Her first care is to ingratiate herself with the inhabitants, and in this she succeeds so well that the workers soon cease to show any hostility towards her. Even the queen grows accustomed to the presence of the stranger and her alarm disappears, but it is succeeded by a kind of despondency. Her interest and pleasure in her brood seem less, and so depressed is she that one can fancy that she has a presentiment of the fate that awaits her. It is by no means a cheerful family, and the gloom of impending disaster seems to hang over it. But while the queen grows more dejected, the *Psithyrus* grows more lively, and takes an increasing interest in the comb, crawling about over it with unwonted alacrity and examining it minutely."

The queen is eventually killed by the parasite, which then begins to

lay her eggs. She is at first very prolific, "but she ages and fails more quickly than the *Bombus* queen. . . . The *Psithyrus* kills the *Bombus* queen before she has laid the full number of worker eggs, consequently nests containing *Psithyri* are not very populous, the number of workers seldom exceeding eighty." Neither queens nor males of *Bombus* are reared in such infested nests, but the workers take to ovipositing. Their eggs would, of course, produce males, but the *Psithyrus* devours them. She "pays close attention to her new-laid eggs for several hours, giving the workers no chance to molest them, but the workers soon get reconciled to them and henceforth they feed and tend the *Psithyrus* brood with as much devotion as if it were their own species; indeed, they seem sometimes to show a greater fondness for it." Sladen's concluding remarks are very interesting in connection with the case of *Psammochares rufipes* and *pectinipes*. He says:

"The origin of *Psithyrus*, more especially of its peculiar parasitical instincts, is an interesting question. If a specimen of *Psithyrus* be compared with a specimen of *Bombus* it is seen that the resemblance is not merely superficial but extends to nearly all the important details of structure, so that it is impossible to avoid the conclusion that *Psithyrus* has sprung from *Bombus*, and this at quite a recent period in the history of life. Moreover, the *Bombi*—and this is particularly interesting—show parasitical tendencies leading to the parasitism of *Psithyrus*. We have seen (pages 55-58) how the *Bombus* queens may enter the nests of their own species and kill one another, and how, in the case of the twin species, *B. terrestris* and *lucorum*, *terrestris* has extended this habit so as to prey on *lucorum*, killing the *lucorum* queen and getting the *lucorum* workers to rear her young in practically the same manner as the *Psithyri* prey on the *Bombi*. It is a remarkable fact that the sting of the *terrestris* queen differs from that of the *lucorum* queen and approaches that of *Psithyrus* in being somewhat stouter and more curved, and having its thickened basal portion more parallel-sided when viewed sideways than in *lucorum*. There is, however, no evidence to show that any species of *Psithyrus* has sprung from the particular species of *Bombus* on which it preys, such resemblances as it may show to it in coat-colour, etc., being pretty clearly attributable to mimicry or exposure to the same conditions of life, and not to ancestry."

Among the social wasps only two parasitic species are known, *Vespa arctica* and *V. austriaca*. The former belongs to our Canadian faunal zone and infests the nests of *V. diabolica*, as Fletcher (1908) has shown; the latter has long been known in Europe where it occurs in the nests of *V. rufa*. Recently Bequaert (1916) has



succeeded in finding *austriaca* in the United States and surmises that it may here be a parasite of *V. consobrina*, "which, although very different in coloration, is very probably the American race or subspecies of *Vespa rufa* L." A good account of what is known of the habits and distribution of *austriaca* may be found in the papers of Robson (1898), Carpenter and Pack-Beresford (1903) and Bequaert. This wasp is so closely related to *V. rufa* that Carpenter and Pack-Beresford regard them as a single species, and the *austriaca* queen as producing both *rufa* and *austriaca* offspring. Their reasons for this assumption are, however, too weak to invalidate the view of the great majority of authors who hold that *austriaca* bears the same relation to *rufa* that *Psithyrus* does to *Bombus*. Both *arctica* and *austriaca* lack the worker caste and eliminate the queens of the colonies which they enter. Males of the host species sometimes develop in colonies infested by *austriaca*, so that, unlike *Psithyrus* and the workerless ants, this parasite seems not to destroy the eggs laid by the host workers.

In conclusion I would record a few reflections that have been suggested by the foregoing survey of the various Aculeate parasites. The tables show in a rather imposing manner that many of these parasites have arisen from their respective host genera, but apart from such forms as *Psammochares pectinipes*, *Vespa austriaca* and some of the parasitic bees like *Perezia* and *Eucondylops* there is little evidence among existing parasites of a direct derivation from their host species. This is what we might expect, for in the first place the origin of most of the parasites is so remote that even if they had remained permanently associated with the species from which they arose, both host and parasite would by this time have diverged in structure to such a degree that their genetic affinities would no longer be clearly discernible, and in the second place, many parasites are probably no longer associated with their original hosts, which have become nearly or quite extinct, so that their parasites have been compelled to adapt themselves to new hosts or cease to exist. Under such circumstances a parasite would naturally attach itself to a species more or less closely allied to its primitive host.

That this has been the course of parasitic evolution seems to be

indicated by the fact, which has not, I believe, been emphasized by other students of the subject, that most of the Aculeate hosts belong to dominant genera. By dominant genera I mean those that are represented by a considerable number of species, some of which are very abundant in individuals and widely distributed as distinguished from genera that are monotypic or represented by few species of rare or sporadic occurrence. Such genera are *Andrena*, *Halictus*, *Anthophora*, *Megachile*, *Osmia* and *Bombus* among the bees, *Vespa*, and *Psammochares* among the wasps, and among the ants *Formica*, *Lasius*, *Tapinoma*, *Pheidole*, *Crematogaster*, *Aphaenogaster*, *Tetramorium*, *Monomorium* and *Leptothorax*. It is, nevertheless, surprising that no hosts of parasitic ants are known to occur in genera like *Camponotus* and *Polyrhachis*, which comprise hundreds of species and are widely distributed, the former in all parts of the world, the latter in the old world tropics. Probably the dominant genera, owing to their abundance in individuals and the wide distribution of their species, would act like great nets set to capture any parasites that have overstepped the bounds of good parasitic manners by bringing their original host species to the verge of extinction. This would account for the close generic affinities which we have seen to be so evident between parasite and host, for a parasite that had endangered or destroyed its original host species would itself more readily escape extinction if the host were already a member of a dominant genus containing many closely allied species, because this would permit a comparatively easy re-adaptation of the parasite to a new host species. Although the parasites would probably differ in their powers of adaptation, the very similar habits of species in the same genus, especially among the bees, would greatly facilitate such a transfer of the parasitic relation.

Still even if we grant that the Aculeate parasite has arisen from its original host species, we are confronted with two troublesome questions, for it will be asked: What induced certain individuals to become parasites on other individuals of their own species? And if a parasite originated in this way, what is to prevent it inbreeding with its host and thus losing its peculiar tendencies by swamping, or "panmixia"? One of the difficulties involved in the first question lies in deciding on the stimuli that would so affect some of the



individuals of a species as to compel them to give up the industrious and nonparasitic habits that have become elaborated and fixed as an integral part of their genetic constitution. I believe, however, that such stimuli exist and that they are frequent and comparatively simple. If we take such a constantly recurring external stimulus as temporary scarcity of prey or food, we can understand how some individuals of a common species that has outrun its food supply or has emerged in seasons or places of scarcity, might find it as easy as advantageous to steal the provisions of other individuals. This is, in fact, a common practice among normally nonparasitic Aculeata, *e. g.*, in *Bembix* and *Psammochares*, in bumblebees, and honey-bees. And if this external is reinforced by an internal stimulus, such as the urgent need for oviposition, we can see how a parasitic group of individuals might readily arise within the confines of a single species. This urgency of oviposition is very apparent in many parasitic Aculeata, especially among the parasitic bees, which often lay several eggs in a single cell of the host, though only one larva is able to develop. *Psithyrus* and some of the parasitic ants seem to reveal the same urgency. It is even probable that this internal stimulus is more fundamental than the external stimulus above mentioned and that it may incite the insect directly to appropriate the provisions collected by other individuals whose ovarian eggs mature more slowly or in smaller numbers. When the parasitic habit is once started it tends necessarily, owing to the saving of energy which would otherwise be expended in work, to accelerate the maturation of the ova and thus to become more and more confirmed by one of the circular processes so familiar to the physiologist.

Urgency of oviposition will, I believe, account also for the many cases in which Aculeates have been observed in the act of appropriating valuable nesting materials or partly constructed nests of other individuals. Fabre (1890) saw wall-bees (*Chalicodoma muraria*) take possession of the partly constructed masonry nests belonging to other females of the colony and destroy their eggs, and Adlerz (1904) observed other bees (*Trachusa serratula*) enter each others' burrows and steal the pine-pitch with which they glue together the pieces of leaves for their nests. Drory (1872) saw

South American stingless bees (*Melipona*) overpower other individuals of their species and bite away the propolis with which their hind legs were charged.

The difference of sexual maturity between parasite and host suggests an answer to our second question, for the time of mating would of course depend on the time of sexual maturity and one group of individuals may be effectually isolated so far as its further phylogenetic development is concerned from another group of the same species, if the mating periods fail to coincide in the two groups. Thus interbreeding of the parasite with the host might be avoided in a very simple manner, and parasite and host, though reared on the same food and in the same environment would nevertheless tend to pursue divergent paths in their subsequent history. It would be interesting, therefore, to collect accurate data on the rate of larval development, and the time of emergence and mating of parasitic Aculeates and their hosts with a view to testing the strength of the hypothesis here suggested.

That certain Aculeates respond so readily and in such a uniform manner to simple stimuli like the urgency of oviposition and dearth of food by becoming parasitic on other Aculeates may be attributed to a peculiar modification of their constitution during their long phylogenetic history, some of the main outlines of which have been clearly revealed by morphological studies. Hymenopterists agree that the higher Aculeates are descended from primitive wasps whose modern representatives constitute the families Scoliidae, Thynnidae and Mutillidae and that their ancestors in turn are to be sought among groups like the Ichneumonidae. The latter have been called parasitic, but it is clear that their larvæ, which feed on the tissues of other insects and eventually kill their hosts are really practicing a refined, protracted and very economical predatism. They may be more properly designated as *parasitoids*, as Reuter (1913) has suggested. The Scoliidae, Thynnidae and Mutillidae, which seek out the larvæ of other insects in concealed places, *i. e.*, in the soil or in nest-cavities, immobilize or kill them by stinging and then deposit their eggs on them, therefore occupy a position, ethologically as well as structurally, midway between the higher solitary wasps and the Ichneumonidae. The higher wasps in constructing nests



and provisioning them with paralyzed insects merely elaborate the same fundamental behavioristic theme or pattern, the main features of which were also retained by the solitary bees even after they had ceased to capture insect prey and had become pollenivorous and nectarivorous. The social wasps and bees have merely modified certain details in the behavior of the solitary species. Among the ants the modifications are more profound, but the most primitive subfamily, the Ponerinae, still exhibits many Sphecid traits. We may assume, therefore, that the ancient parasitoid habits of the Ichneumonid ancestry still abides as a latent, phylogenetic memory, or mneme, in the constitution of the whole Aculeate group. Hence it is not surprising that this mneme can be revived in response to such recurrent external and internal stimuli as dearth of food and urgency of oviposition. Under these conditions the solitary Aculeate readily becomes parasitic and reverts to a type of behavior essentially like that of the Mutillidae, Thynnidae and Chrysididae. In the parasitic social Aculeates new behavioristic modifications have developed as the result of the complex and peculiar living environment presented by the social habit of the host, the trophallactic relations of the mother insect and her offspring and the existence of a worker caste.

The general conclusions that may be drawn from the foregoing survey of the parasitic Aculeata in particular and of insect parasites in general may be stated as follows:

1. We may distinguish two intergrading types of parasitism among insects. One of these is true parasitism and is represented by the lice, fleas, Mallophaga, many Diptera (Æstridae, Pupipara) and some Hemiptera, which live on mammals and birds and do not destroy their hosts. The other is parasitoidism, which is really a refinement of predatism and is eminently characteristic of large sections of the Hymenoptera and Diptera (Tachinidae). It leads sooner or later to the death of the host. The difference between the two types is largely due to differences in the size and vigor of the hosts.

2. Parasitoids are of two classes, one of which is best represented by the so-called Parasitica among the Hymenoptera and the Tachinidae among the Diptera, which have no genetic relationship

with their hosts. The other class of parasitoids is represented by the Aculeates which have sprung directly from their host species (intraspecific parasitoids), though they may subsequently acquire hosts among other species of the same genus or of other genera and may in turn be the ancestors of parasitic species.

3. The derivation of all the existing Aculeata from primitive insectivorous wasp-like ancestors may account for the retention of a rather uniform pattern of behavior among the parasitic species. The parasites, both among the solitary wasps and the solitary bees, behave in a very similar manner, though the former are reared on insect prey, the latter on pollen and honey. In both groups the object of the parasite is to secure the provisions accumulated by the host for its own progeny. This involves a destruction of the egg or young larva of the host. The social parasites, however, have passed beyond this destruction of the host brood to a stage involving the fostering of the host brood as a means of insuring the rearing and alimentation of their own young. This change may have been due in the first instance to the formation of trophallactic relations between the parasite and the host brood.

4. The origin of parasitism among the Aculeata may be attributed to urgency of oviposition and temporary or local dearth of the supply of provisions for the offspring.

5. In all the different forms of parasitism among the Aculeata, there are traces of the primitive predatism or parasitoidism from which it arose, although in some of the social parasites this is represented only by the aggressive or conciliatory intrusion of the recently fecundated female into the host colony. Even the more extreme forms of behavior, such as those of the temporary and permanent social parasites, were derived from predatory behavior like that manifested by *Formica sanguinea* and its various subspecies and varieties.

6. Although many cases of parasitism are known to occur among the Aculeata, and although many others will doubtless be discovered in the future, nevertheless the total number must be small in comparison with the thousands of nonparasitic species. Contemplation of such a series as we find among the ants, beginning with *Formica sanguinea*, which is an abundant, vigorous and aggressive species



and ending with *Anergates atratulus*, a small, sporadic, and apparently evanescent species, without workers and with wingless, nymphoid males, suggests that parasitism among the Aculeates tends to such extreme specialization ("degeneration") as to lead to extinction. If we possessed a knowledge of the whole evolution of the Aculeate group, we should probably find that the total number of parasitic species which it produced during the ages was very great, but that the vast majority of them, after reaching the *Anergates* or a similarly specialized, or degenerate stage, lingered on precariously for a time and then disappeared.

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## THE RELATION OF THE DIET TO PELLAGRA.

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Pellagra has long been suspected of being caused by faulty diet, and the eating of maize, particularly moldy maize, has been considered by some students of the disease to be the specific cause. The studies of Dr. Goldberger of the Public Health Service have eliminated corn as a causative agent in the etiology of this disease. Funk in his enthusiasm over the "vitamine" hypothesis adopted the view that not only beri-beri but scurvy, rickets, and pellagra were each due to the lack of a specific "vitamine" in the diet. He further assumed, in order to explain the conflicting results in some of his experimental work, that other "vitamines" necessary for maintenance and for growth respectively are necessary in the food supply. We have attempted during the last two years to discover the exact nature of the deficiencies of such diets as are in common use among the people of the cotton mill villages in the South where pellagra is very common. We have employed what may properly be described as a biological method for the analysis of a food stuff or of mixtures of foods. This consists in feeding any foodstuff which is faulty in one or more respects to a group of animals, and in other experimental groups the same food supplemented with single or multiple food additions, such as pure protein, one or more pure mineral salts, one or more of the still unidentified dietary factors in the form of suitably prepared preparations. We have throughout these studies employed as a working hypothesis the assumption that the essential constituents of an adequate diet are protein of suitable quality and quantity, an adequate supply of the necessary inorganic elements in suitable combinations, an adequate energy supply in the form of protein, carbohydrate, and fat, and two as yet chemically unidentified dietary essentials which we have



designated "fat-soluble A" and "water-soluble B." The lack of the former leads to the development of a specific eye trouble which seems to be accurately described as a type of xerophthalmia. The factor water-soluble B is we believe identical with the substance which prevents or cures the disease beri-beri characterized by general paralysis which is common in the Orient.

Our experimental studies have now progressed so far as to enable us to assert with confidence that a satisfactory diet cannot be secured from mixtures containing any number of seeds or products derived from the milling of seeds together with tubers, edible roots, and meats. The vegetable foods which may be classed as seeds, tubers, and roots are all functionally storage organs, and their content of active protoplasm is relatively small in comparison with their bulk because of the large amount of reserve food material laid down in them. They may be sharply contrasted with the leaf of the plant, which except in special cases is not a repository for reserve proteins, carbohydrates, and fats, but represents, aside from its skeletal tissues, functionally active protoplasm. The leaf has very different dietary properties from those possessed by the tissues which are modified as storage organs, and in many instances at least represents complete foods for those types of animals whose digestive tracts are so capacious as to permit them to eat a sufficient amount of bulky material. We have been able to prepare fairly satisfactory diets for an omnivorous animal, the rat, from these two types of vegetable foods together, *i. e.*, leaves and seeds, but never from the group of vegetable foods which are functionally storage organs.

From this experience we have been led to differentiate sharply between two classes of foods which are usually collectively designated as vegetables. Leaves are constituted so as to correct the dietary deficiencies of the storage tissues, whereas the seeds, tubers, and roots fail to supplement mutually each other's deficiencies with respect to either the inorganic moiety or the fat-soluble A. They do in some degree mutually enhance the quality of each other's proteins, but to a lesser degree than we had supposed before the completion of a large amount of experimental work directed toward the

quantitative comparison of the protein mixtures derived from pairs of seeds in considerable number.

Mixtures of seeds, or of seeds, tubers, and roots, will in all cases require supplementing with respect to calcium, sodium, and chlorine among the inorganic elements, and fat-soluble A. In most such mixtures the quality of the proteins will likewise be sufficiently poor to require improvement before the optimum well-being can be secured.

We are now in possession of a considerable amount of knowledge concerning the distribution of the dietary factor, fat-soluble A, in animal tissues. The body fats of the ruminants will probably always be found to be richer in this substance than the body fats of the omnivora because of the greater intake of it in the food. Muscle tissue has been found to be very poor in fat-soluble A, but the fats from the glandular organs, *i. e.*, intracellular fats, are a good source of it. It follows, therefore, that muscle tissue such as round steak should not supplement mixtures of vegetable foods which belong to the storage organ group with respect to fat-soluble A, and in our experience this proves to be the case. The inorganic content of muscle tissue resembles in a general way that of the storage organs of plants except in its very low content of magnesium. It is too poor in calcium, and to a lesser degree in sodium and chlorine, to support the optimum well-being in an animal. Muscle tissue fails to supplement the seeds, tubers, and roots on the inorganic side. The protein content of muscle tissue is high and the proteins are probably of high biological value, and, except as respects palatability, it is only in improving the quality of the protein content of the ration that the addition of meats of this class enhances the value of a mixture of products derived from the storage organ group of plant products.

These considerations indicate the basis for our distinction between two groups of foodstuffs. One of these, which includes milk, eggs, and the leafy vegetables, we have designated as "protective foods," in order to call attention to their special importance in the diet. They are protective in that they are so constituted with respect to their inorganic content, content of fat-soluble A, and the quality of their proteins that they correct in great measure when



used in sufficient amounts the faults of the remainder of the food mixture irrespective of the extent to which it is derived from either seed, tuber, or root products. We have been able to plan satisfactory diets of naturally occurring foods only by the inclusion of one or more of these protective foods. The other group of natural foodstuffs includes all seeds and seed products, such as the cereal grains and their milling products (wheat flour, corn-meal, polished rice, etc.), the legume seeds, tubers, edible roots, nuts, fruits, and such cuts of meats as come from muscle tissue.

In all cases where we have attempted to correct the dietary deficiencies of a seed mixture by the addition of leaf only we have not secured results so good as with milk, especially with such amounts of leaf as would be acceptable in the human diet. The leafy foods are eaten by Europeans and Americans only in a very water rich condition, and it is difficult to secure the consumption of enough to correct the deficiencies in the remainder of the diet. With animals, when we have fed dry powdered mixtures containing as much as 25 to 40 per cent. of the diet derived from leaf and the remainder from plant products of the storage organ class, the nutrition has been very good in some instances, but not all combinations will be equally valuable. Eggs are decidedly poorer in calcium than are the leaves or milk, when only the part exclusive of the shell is considered. The shell serves as a source of lime to the developing chick. Eggs do not, therefore, supplement food mixtures derived from storage tissues with respect to calcium to the degree that milk and leafy vegetables do.

Even in such types of diet as contain one or more of the protective foods in fairly liberal amounts, it is certain that for such rapidly growing species of animals as the hog and rat the inorganic content is not entirely satisfactory, although it may be good enough to enable the animal to perform all the functions of growth and reproduction in a way which, in the absence of definite knowledge of what the species is capable of, we should regard as normal. We have been accustomed to regard as normal an achievement in vigor and well being both in man and animals which falls far short of that seen in exceptional cases. The most important inorganic deficiency in seed, tuber, and meat mixtures is calcium, and this is so pro-

nounced that we are of the opinion that even in those human dietaries in which such calcium-rich food as milk is used in fair liberality, the intake of calcium may be still below the optimum, and that a direct addition of this element in the form of the carbonate or lactate might be of distinct benefit in human nutrition except perhaps in those regions where the water is unusually rich in calcium salts. Since civilized man usually adds sodium chloride to his foods to suit the taste, the shortage of sodium and chlorine in the diet of man presents no problem. An addition of calcium could be most conveniently made to our foods through the use of a mixture of equal parts of common salt and of calcium carbonate in the kitchen and on the table.

A question which has never been answered to the satisfaction of physiologists is: How much protein should the diet contain in order to maintain physiological well being? At about the time when the question was being most discussed, the chemistry of the proteins was developed to a point which made it clear that there were great differences in the biological values of the proteins from different sources, depending on their yields of certain amino-acids. This makes futile any attempt to establish a particular intake of protein which may represent the minimum, optimum, or maximum amount consistent with maintenance of "normal" vitality and health. The quality of the proteins must be known before anything can be said about the amount of protein necessary. From biological tests we now know that the proteins of the pea or navy bean are worth only about half as much for growth in the rat as are equal amounts of proteins from one of the cereal grains, and that the latter have about half the value for the conversion into body proteins which can be shown for the proteins of milk. The relative values of the proteins from different sources, as well as the absolute values of certain of them, are just now becoming appreciated.

There are two opposing views regarding the amount of protein which will produce the best results. Those who advocate the low protein diet point to the "specific dynamic action" of protein, through which it stimulates metabolism. They believe that a high consumption of protein furnishes pabulum for the development of an excessive growth of putrefactive bacteria, with the result that



toxic or irritating products of the degradation of certain amino-acids are absorbed in amounts sufficient to cause damage to the tissues. It has been recommended that man should, in adult life, take only such an amount of protein as will cover the endogenous loss due to tissue metabolism, together with a not well-defined "margin of safety." The opponents of this view regard a liberal protein allowance as essential to vigor and aggressiveness, and point to the use of liberal amounts of meat by the peoples who have been characterized by greatest achievement. Among all the progressive peoples of the world the food supply is derived to a greater or less extent from daily products, and this portion rather than the meat eaten we have come to regard as of peculiar importance in improving the quality of the diet. In order to test this question we conducted a series of experiments, employing rats which were about nine months old, or about one fourth through the normal span of life for this species, and were in excellent nutritive condition. They were fed diets which were fairly satisfactory in all respects except that the protein content was not far from the actual amount required for the maintenance of body weight for a few weeks. We observed unmistakable signs that the vitality of the animals was rapidly lowered on such a dietary régime. This was shown especially by the rapid aging and short span of life. Even though the initial body weight was approximately maintained for a period of three months or more, distinct signs of aging were always apparent within five to ten months. Three months in the life of a rat correspond to about 8.4 per cent. of the average span of life. It can be readily appreciated that if harmful effects in corresponding degree follow the adherence by man to such low protein diets they would not become apparent within the time covered by any experiment yet conducted upon a diet squad, few of which have been restricted to any experimental diet beyond six months. A reputed satisfactory outcome of such experiments cannot be accepted as evidence that men on diets which furnish but a small margin of protein over the actual maintenance requirements are so nourished as best to promote health. Aging at two to four times the rate observed in the most satisfactorily nourished would escape observation in any experiment on man with which we are familiar.

The results of experiments with grown men restricted to experimental diets for a few weeks or months do not form a safe basis for drawing conclusions as to the quality of the foods employed. Certain conclusions may be warranted from general observations on children living on faulty diets, and important deductions may safely be drawn from the experiences of large groups of people living upon more or less restricted lists of foodstuffs. Beyond this we must be guided in human nutrition by the results of animal experimentation, in which the conditions can be made sufficiently rigid to bring into stronger contrast the faults of certain types of diets as contrasted with others. It is certain that the injurious effects of certain dietary practices are very real and yet not promptly apparent. The debilitating effects of faulty diets may vary in their severity from such as will produce polyneuritis or xerophthalmia or scurvy within a few weeks, at one extreme, to such as will cause nervousness and restlessness in varying degree, susceptibility to disease, and the acquisition of all those characters such as roughness of the skin, thinness and coarseness of hair, and attenuation of form which accompany the process of aging at a distinctly greater rate than would be the case were the diet of a highly satisfactory character.

We have much evidence that in case there is a close approximation of the actual physiological minimum for any factor during growth, such as one or more of the essential inorganic elements or one of the unidentified dietary essentials, lack of ability to meet the more strenuous demands of reproduction and the suckling of young will be observed, and the tendency will be great for the individual to be carried off suddenly either by disease, or, as frequently happens, by causes which are not readily determinable.

All our experience with diets of low protein content have indicated that animals do not remain in a state of optimum well-being even when the content of protein is sufficiently high to maintain in certain individuals the initial body weight over as much as 10 per cent. of the normal span of life. We believe that health and vigor are promoted by a liberal intake of protein of good quality better than by any diet in which there is a tendency towards parsimony with respect to this dietary factor. It should not be lost sight of, however, that there are other factors in nutrition which are of equal



importance with protein, and that if the optimum well-being is to be attained the diet must be rightly constituted with respect to all its parts. In addition to this the prompt elimination of the fecal residues is essential and is a great relief to the tissues of the entire body.

With an understanding such as we now have of the nature of the faults of diets of different types, and an appreciation of the fundamental importance of deriving the constituents of the diet from the right sources, this being of much greater importance than composition as revealed by chemical analysis, one is in a position to interpret the relation of pellagra to diet.

Goldberger has emphasized the fact that the diet of those living in districts in which pellagra is common is lacking in sufficient amounts of certain foodstuffs, especially milk, eggs, meats, and the legume seeds. In many instances bolted wheat flour, degerminated corn-meal, polished rice, sugar, syrups, or molasses, sweet potatoes, and meat, principally pork, form almost the entire list of foods eaten by families during the winter season, at the end of which new attacks of pellagra are regularly seen. From what has been said it will be evident that the diet of the pellagrous is deficient in four respects, and that the nature of these is well understood. They are the deficiencies of the plant products which belong to the storage organ group, but more pronounced because of the prominent place which milling products, which represent the endosperm of the seed, find in such diets. Products such as bolted flour, degerminated corn-meal, and polished rice are decidedly poorer in inorganic elements than are the seeds from which they are derived; their proteins appear to be of poorer quality than are those of the cell-rich structures near the periphery, or of the germ, and they are almost devoid of fat-soluble A and very poor in water-soluble B. Whereas diets derived from whole seeds, tubers, and edible roots contain sufficient phosphorus to meet the requirements of the most rapidly growing species of animal, such as the rat, and the limiting inorganic elements are calcium, sodium and chlorine, it may be that in diets in which the degerminated and decorticated cereal products are employed in liberal amounts, and where in addition starch, sugar and molasses are regularly used freely, phosphorus or iron or both may likewise become important deficiencies.

Goldberger attempted to solve the problem of whether pellagra is due to lack of something essential in the typical "pellagrous" diet by a direct experiment on man. He restricted men to a diet prepared from bolted wheat flour, degerminated corn-meal, polished rice, starch, sugar, syrup, pork fat, sweet potatoes, cabbage, collards, turnip greens and coffee, and at the end of five and a half months five of the eleven men who took this diet were diagnosed as exhibiting incipient signs of pellagra. That the disease was actually produced has been emphatically denied by McNeal.

In another experiment Goldberger and fifteen of his associates made heroic attempts to infect themselves with material from the lesions of pellagra, and with excreta from pellagrins, but without success. The experimenters were, however, taking a diet of good quality while these attempts were being made.

Still more convincing evidence that the diet is at least an important predisposing factor in the etiology of pellagra is furnished by the experience of Goldberger in improving the diets in institutions in which the disease was common. These diets were observed to consist largely of degerminated seed products, tubers or roots, and fat pork, together with minimal amounts of leafy vegetables, fruits, eggs, meats, and milk, and the legume seeds. On modifying the diets of orphanages and of an insane asylum by the addition of lean meat, milk, eggs, and peas or beans, the condition with respect to pellagra steadily improved, and the disease promptly disappeared. New cases were admitted from without and the sick were mingled with the well, but after the improvement of the diet no new cases developed.

Those who have had extensive experience with pellagra are in agreement in the matter of the fundamental importance of dietary treatment together with any other method of management of pellagrins, and the assertion has been made by Roussel that without dietary measures all remedies fail. The results obtained by Goldberger point clearly to the belief that the disease develops because of some one or more faults in the diet. They afford no basis, however, for judging as to the nature of these faults, whether they are in the nature of a lack of a sufficient amount of one or more chemically unidentified dietary essentials of a specific character, as is



known to be the case with beri-beri and the xerophthalmia of dietary origin, or whether pellagra may be the result of taking a diet faulty in respect to the quality or quantity of protein, relative shortage of one or more of the essential inorganic elements, or of the recognized unidentified dietary essentials as contributing factors.

In his earlier papers Goldberger expressed the view that: "On the whole, however, the trend of available evidence strongly suggests that pellagra will prove to be a 'deficiency' disease very closely related to beri-beri." Chittenden and Underhill reported the production in dogs of a condition suggestive of pellagra in man by restricting the animals for periods of from two to eight months to a diet of crackers, peas, and cottonseed oil. They formulated the conclusion that: "From the facts enumerated the conclusion seems tenable that the abnormal state may be referred to a deficiency of some essential dietary constituent or constituents, presumably belonging to the group of hitherto unrecognized but essential components of an adequate diet."

We have reported elsewhere the results of a study of the nature of the dietary faults of a mixture of bolted wheat flour, peas, and cottonseed oil, and found that it was an incomplete food, but that it was rendered complete for the support of normal growth in the young rat by the addition of purified protein, certain inorganic salts ( $\text{NaCl}$  and  $\text{CaCO}_3$ ) and fat-soluble A (in butter fat). It is of course not satisfactorily established that the condition produced in dogs by the diet of Chittenden and Underhill was actually the counterpart of pellagra in man, strikingly similar as the results appear. We hold the view that if the condition produced in the dogs of these investigators is actually to be regarded as experimental pellagra, it cannot be regarded as caused by the lack of an unidentified dietary essential, since the only one of these necessary for completing the diet (for the rat) is that contained in butter fat, and the latter substance is not curative for any condition resembling pellagra, but for a specific eye disease, xerophthalmia.

In his most recent studies Goldberger and his associates examined the diets of pellagrous and non-pellagrous families in villages in South Carolina, and found that the diet of the non-pellagrous contained more milk, fresh meats, eggs, butter, and cheese than did

the diets of pellagrous families, and that calorific value of the diets of the former households was somewhat higher than of the latter. Animal proteins were eaten more liberally and cereal proteins were eaten less abundantly by the non-pellagrous than by the pellagrous households. The pellagrous households had a distinctly smaller supply of fat-soluble A, and a somewhat smaller supply of water-soluble B than did the non-pellagrous, and the inorganic content of the diets of the latter were of less satisfactory character than those of the former households. We do not regard a moderate shortage of one or another of the chemically unidentified dietary factors as of greater gravity than faulty character in any other dietary factor. Our studies of the several foodstuffs lead us to agree with Goldberger's interpretation of the quality of the diets of pellagrous and non-pellagrous households in all respects.

From the observations which we have made concerning the chemical factors which the diet must contain in order to be adequate for the support of growth in the young, or the maintenance of physiological well-being in the adult, together with the results of our studies of the qualities of each of the more important kinds of natural foodstuffs, we are not able to account for the etiology of pellagra on the assumption that it is a disease which is due to the lack of a specific substance or substances of unknown chemical nature, as are without question beri-beri and xerophthalmia. This follows from the fact that, with the exceptions of certain manufactured food products which are derived from the endosperm of the decorticated grains, any natural foodstuffs of the class of seeds, tubers, edible roots, or leafy parts of the plant, are so constituted that they can be supplemented by means of three kinds of purified food additions of known nature: viz., protein, certain salts, and fat-soluble A, so as to be complete for the nutrition of the young rat throughout the growing period. This has been demonstrated to be true not only for each of the ordinary human foods but likewise for such mixtures as form the monotonous diets of the pellagrous.

It is necessary, therefore, that we choose between two alternatives in arriving at an opinion concerning the etiology of pellagra. We have the assurances of Goldberger and his associates that a diet such as that described on page 49, and having the qualities described



in the preceding paragraph, has produced incipient pellagra experimentally in man, but this claim has been disputed by other competent observers. In our experimental work with the diet of peas, crackers (wheat flour and fat), and cottonseed oil, which in the experience of Chittenden and Underhill produced in dogs a condition resembling pellagra in man, produced in rats only general malnutrition, without the skin changes, diarrhea, or pathological changes in the mucosa of the alimentary tract. Are we to accept the view that pellagra is actually produced by a deficiency of something necessary to the normal nutrition of man but not necessary for the rat? The possibility that the dogs of Chittenden and Underhill were infected is not excluded, and an infectious agent may well have established itself in animals restricted to a diet so faulty as one derived from crackers (wheat flour and fat), peas, and cottonseed oil. Goldberger seems to have safeguarded his experimental men against infection, and it is unfortunate that a sufficient number of undisputed authorities were not called into consultation to forestall the possibility of a question arising concerning the accuracy of the diagnosis of pellagra, such as McNeal has raised.

We are left in the situation which has arisen in the discussion of the etiology of scurvy. It has been clearly shown that there is no difficulty in repeating the experimental work which demonstrated that a guinea pig will develop severe scurvy (or some syndrome resembling it) on a number of diets on which the rat will thrive during the growing period. Does this mean that the guinea pig requires one or more chemical complexes for its nutrition that are dispensable to the rat? There is no doubt that the guinea pig normally takes a diet rich in succulent vegetables, and which produces bulky, easily eliminable feces. The rat and swine, as well as man, thrive on certain diets which leave little indigestible residue. Such special requirements in the guinea pig make it next to impossible to compare this species with man or the rat in similar dietary studies. The experimental data obtained with the guinea pig must be used with caution in reasoning concerning the etiology of human scurvy.

In our attempts to produce in animals a condition analogous to pellagra in man we have not been successful, but have observed only a generalized poor condition instead. The evidence is practically

nil that Chittenden and Underhill's dogs suffered all the pathological changes which they record solely as the result of chemical faults in the diet. Our experiments with their diet show it to be incapable of maintaining satisfactory nutrition because of faults in the dietary factors. The possibility of an infection in their animals is not excluded, and is indeed rendered probable if we grant that lowered vitality predisposes to infection. These reasons together with the lack of positive proof that the men restricted in Goldberger's experiments to a diet similar to that described were actually developing pellagra, warrant, we believe, our accepting as probably correct the conclusions of the Thompson-McFadden Commission and of Jobling and Peterson that pellagra is caused by an infectious agent, and that unless it has been introduced into a district there may develop such a condition of lowered vitality from faulty diet or other debilitating influence as would predispose one to an attack, without the appearance of the disease. The debilitating effects on animals of diets derived from cereals, tubers, roots, and any food products formed from the milling of grains together with legume seeds and meats, are so striking that we believe similar diets would produce in man a susceptibility to infectious diseases such as tuberculosis or pellagra. We have come to hold the view, as the result of our studies of diets of the type common in pellagrous households, that the predisposing influence for both is in general the same, and the character of the unsanitary conditions surrounding the individual may determine which of these two diseases he will develop.

From the studies which we have described elsewhere we are enabled to point out definitely the relative values of several foods as correctives in the diet of the pellagrous. Hitherto the legume seeds and lean meat were classed with milk and eggs in this respect, and nothing was said about the unique qualities of the leafy vegetables as supplements for food mixtures derived from plant products of the storage organ group. It is clear that the most important food to be recommended for consumption in pellagrous districts is milk, because of its cheapness as compared with the same protective value in foods from other sources and its threefold corrective character as contrasted with meat which enhances the type of diet found in the pellagrous household only with respect to the protein factor, and



eggs which are not so good as milk because of their lower calcium content. The legume seeds, notwithstanding their high content of protein, are without any appreciable value for improving the diets which predispose to pellagra, because of the poor quality of their protein and their failure to supplement a diet derived from vegetable foods of the storage tissue class in other respects.

Both meats and eggs are more expensive sources of protection against faulty diet than milk. An effective campaign of education should be conducted in all districts where diets of a character likely to predispose to pellagra are common, informing the people about the great benefits to health from regular and very liberal use of leafy vegetables. This would be a movement toward the establishment of dietary practices resembling those of the more nearly vegetarian groups of Chinese and Japanese, and if in addition the inclusion of a suitable amount of milk in the diet can be secured, not only would pellagra disappear, but the general health of the people would be promoted.

The prevalence of pellagra in certain parts of the South rather than in other sections of the country is probably closely connected with the development of the modern milling industry. This places in the grocery store the degerminated and decorticated part of the grain. The rise of the sugar industry offers for human consumption both sugar and molasses in quantities unheard of until recent years.

The widespread practice of growing a cash crop (cotton), and of depending on the retail store for the greater part of the food supply rather than of engaging in diversified farming appears to be in great measure responsible for the existence of pellagra. The food products which can be handled commercially without hazard are not in general satisfactory foodstuffs unless properly supplemented with certain others which correct their deficiencies.

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## EVOLUTION AND MYSTERY IN THE DISCOVERY OF AMERICA.

By EDWIN SWIFT BALCH.

*(Read April 24, 1919.)*

It is usually supposed that the American continent was revealed to Europeans by an incident known as the discovery of America. This is assumed to have taken place almost with the unexpectedness and rapidity of a stroke of lightning or the breaking of an egg. The reality, however, is quite different. The opening up of the North and South American continents to the white races of Europe is due to a long series of events and movements, that is to evolution, and not to a single occurrence ideally fathered in one individual's brain and which his genius brought from an ideal stage into a concrete matter of fact one. Not only was it a process of evolution which made known the New World to the Old World, but it was an evolution so long drawn out that it was entirely unnoticed at the time and as a result many of its steps are forgotten and much of it is most hazy. Indeed the most salient point in regard to the recognition by Europeans of the existence of the American continent is that it is an evolution veiled in mystery.

All geographical discovery indeed is an evolution and this evolution proceeds from many causes. One of them is the movement and migrations of peoples. People slowly filter into lands new to them, discovering as they go new sites in which to hunt and in which later to dwell. They are not on the outlook for discoveries proper, they are not searching to penetrate the secrets of the unknown: they are merely seeking new spots in which to live, because for some reason they are driven out of their former homes. Overpopulation it may be, or the drying up of the water supply and the destroying of the soil by cutting down the forests, or some other cause; but whatever the cause something impels certain peoples



to move into fresh fields and pastures new and by so doing they open up new lands and new waters.

The most potent cause acting on the individual to make him a geographical explorer is the fascination of the unknown. Some men seem impelled by the spirit of curiosity to pry into things hidden from their ken. When more highly developed this changes into the spirit of research and those smitten by it delve into the unknown with the scientific purpose of adding to the sum of human knowledge. In some men this spirit manifests itself in trying to unveil the untouched parts of the earth, seas or lands, even if merely some small untrodden mountain peak, to which the fascination of the unknown lures them on with irresistible appeal.

As a sequel to this, though in lesser degree, a good deal of exploration is due to the desire for adventure or sport which some men are imbued with. Without any special curiosity to seek new parts of the earth, they are driven by their nature to hunt or to fish. And in their wanderings carried out to gratify other tastes, incidentally frequently they make geographical discoveries which later comers complete and verify.

An extremely active and effective agent in bringing about knowledge of the surface of the earth is commerce. Peoples search for greater food supplies; they search for new countries from which to bring home useful products; they search for new markets in which to sell their own productions. Merchants put up the cash and sea captains and sailors start off to make that cash fructify. Many voyages have been made in past centuries in which geographical discovery was entirely secondary to commercial gain and yet in the pursuit of the latter some rich prizes in exploration have fallen to traders who cared but little for them. Some men have sought new fishing grounds; others have followed fur-bearing animals; others again have gone to enslave their fellow men. Sometimes successful, sometimes unsuccessful in their quests, these men, in a purely accidental way, have revealed many a new land or sea to their fellows.

What we know of past geographical discovery depends mainly on two sets of evidences: written records and maps. A trifling part

of it depends on archeological evidence and another on tradition. The most important evidences are: the narratives of travelers themselves or the accounts written of travelers by their contemporaries; maps. In many cases a map is the only record. It delineates a land or a sea of which there is no written account dating back as far as the date of the map. And when one finds on a map some earth feature correctly placed and even if one knows nothing of its discovery or its discoverer, it is difficult to refuse to recognize that that particular bit of the world had been seen and reported by some perhaps forgotten person. Maps in fact are something like portraits. A genuine portrait is hard to deny. So valuable as identifications are photographic portraits, that now they are placed on passports in some countries. If at all accurate, maps are among the most uncontrovertible evidences of geographical discovery. And it is precisely on maps that many of the riddles connected with the unfolding of the geography of the American continent are presented.

The earliest European invaders of the American continent found it tenanted by native races. Who were these races and when and where did they come from? While no positive answer can be given to these questions, yet we know now that our American natives have been here a long, long time, and that they had been acted on by the force of evolution for many millenniums before the white race came to contest with them the ownership of the lands stretching from Grant Land to Tierra del Fuego. The ancestors of our historic Indians and of our present Eskimo were, of course, the real original inhabitants of America, but when and how they became so is at present unknown to us. Were they autochthones? We do not know! Or did they wander in from Asia? Again we do not know! But if they did the latter, and it certainly seems the most probable, then they spread over the American continent by migration and, in a certain sense therefore, were its original discoverers.

The evolution of the European invasion of America, as far as accessible records show, begins in early historic times. Between the years 1000 and 500 B.C., some Phœnicians circumnavigated



Africa. They started from Egypt, went down the east coast of Africa, rounded the Cape of Good Hope, and returned via the west coast of Africa and the Straits of Gibraltar. Their chronicler, Herodotus, unfortunately gives them a very meager notice. Nevertheless theirs was the first historic voyage on the Atlantic Ocean and the first recorded step leading to the discovery of America by the peoples of Europe.<sup>1</sup>

The next attempts at exploration in the Atlantic of which we have any record are the journeys of the Carthaginians Hanno and Himilko. Hanno sailed from Carthage about 500 B.C., passed through the Straits of Gibraltar and turned south along the African coast. He reached a country where he found hairy men with some of whom he had fights in which he killed three whose skins he brought back to Carthage where they long hung in one of the temples. These hairy men are by some writers surmised to have been chimpanzees or gorillas. At about the same time as Hanno, Himilko is said to have made a journey beyond the columns of Hercules, to have turned north and to have reached a land where there was much tin. This probably was Great Britain. The Phœnicians, however, may have known more about the Atlantic than has come down to us in any record, for it is said that coins from Carthage and other towns in North Africa have been found on the island of Corvo, the most westerly of the Azores.

The fourth recorded journey of exploration in the Atlantic is the voyage of Pytheas. A Greek, of Massilia (Marseilles), he sailed through the Straits of Gibraltar about 350 B.C., turned north and reached the shores of Britain. Along these he sailed far to the north, until he arrived in a region where a sort of thickening of the elements, which he said resembled a marine lung, filled all space. It is surmised that he had reached the rains and fogs of northern Scotland and perhaps of the Orkneys and Shetlands, a surmise the more probable as he speaks of the sun dipping under the horizon for only a short time.

<sup>1</sup> A few references are given with this paper in regard to facts only lately brought into prominence. For the other facts mentioned, references by the hundred may be found in Edouard Charton's "*Voyageurs Anciens et Modernes*"; in Justin Winsor's "*Narrative and Critical History of America*"; and in the works of A. E. Nordenskjöld and Henry Harrisse.

The Romans, through Julius Cæsar's conquest of Britain, made a step forward by clearing up the geography of the British Isles. After their departure, when Britain proper went into anarchy, for several centuries Ireland remained in a decidedly advanced state of culture. Ireland also is the most westerly outpost of Europe. These two factors combined lend authority to the statement in one of the Norsk Sagas that when the Vikings first reached Iceland in the ninth century A.D. they found some Irishmen settled there. The importance of this is obvious. Iceland is much nearer to America than it is to Europe. From a navigator's point of view it is an American island. Any people who reached Iceland was bound sooner or later to reach America. And effectively in another of the Norsk Sagas, there is a mention of a Great Ireland far in the west, which may refer to Greenland. But while it is impossible to say exactly what the Irish did do or where they got to, it is nevertheless unquestionable that they forged an important link in the evolution of the discovery of America. Indeed their discovery of Iceland seems to warrant considering them the first European discoverers of an American land.

The Norsemen or Vikings it was who first made recorded explorations beyond Iceland, which they reached by the ninth century A.D., and where they settled, lived and quarrelled. They left semi-historic and semi-poetic narratives, the Sagas, of some of their doings and from these we can glean a good deal about their explorations which if not historically accurate, is at least too accurate not to be based on actual facts. It was some time before the year 1000 A.D. that one of the Vikings reached Greenland. Did he sight Greenland from Iceland, which is said to happen occasionally in the clearest weather? At any rate a certain Gunnbiorn is claimed to have sighted Greenland before 900 A.D. Or did the first discoverer have a quarrel and was he driven out of Iceland? There is a story to that effect about Eric the Red, who is believed to be the first Norseman who actually landed on the shores of Greenland. He was followed by his son Leif Ericson, by Bjarni Herjulfson, by Thorfinn Karlsefni, and others. Settlements were formed in Greenland and further voyages were made to Markland, to Hellu-



land and to Vinland. All these places were real, were genuinely reached, but unfortunately their location is uncertain. Some writers think the Vikings reached Labrador and Newfoundland; others think they got as far as Cape Cod; and to this view I am myself inclined. But from the evidence, the most southern locality reached by the Vikings can not be positively identified.

But in Greenland the Vikings left positive traces of their sojourn in the shape of ruins. Some of these are the remains of churches, and it is known that there were missionaries and religious men among them. And towards the years 1100-1200 A.D., there is no doubt that there was intercourse between the Greenland settlements and Iceland. Slowly however, darkness settles over the Greenland Vikings. Did they all come back: did they die out: or did they migrate to the West? We do not know. Only a few years ago, some rather light-haired Eskimo were found near Coronation Gulf and were surmised to be descended partly from the Greenland Vikings. At any rate these latter were gradually forgotten in Europe, where Greenland remained on the maps, however, as a peninsula attached to Northern Norway, for instance in a map of 1368 and in the Ptolemy of 1486. All this is hazy, it is mysterious, but nevertheless it is certain that the Norse Vikings were genuine European invaders of the New World.

One tale there is that about 1170 A.D. a Welsh chieftain, by the name of Madoc, reached the coast of North America. This legend is unsupported by any evidence save that there is a similarity between some half a dozen Welsh and American Indian words, and this evidence is so perfectly flimsy, that it seems safe to relegate a Welsh discovery of America to the realm of fairy stories.

It was not, however, the voyages of the northern Vikings, it was the voyages of the Portuguese, Spaniards and English, which led to the peopling of the American continent by the European races. While striving to reach the East Indies by sailing west, the hardy mariners from southern and western Europe found the way barred by the West Indies or New World. Already in the fourteenth century, it is said as early as 1350, the Portuguese began to make gradually lengthening voyages to the islands off the north-west

coast of Africa. Why did they do so? It seems as if there were several causes. Of course there was the fascination of the unknown, the joy of discovery, but undoubtedly the main cause was commercial. And this commercial impetus apparently was due to the Crusades and to the invasion of Europe by the Turks. For those wars, in which Christians and Moslems smashed each other's heads for the glory of God as they still only yesterday were doing in the Balkans, blocked the commerce of Venice with the East and led the Portuguese and the Spaniards to seek a way around Africa to obtain the spices of India. Thus although the great Portuguese explorations were not wholly due to the blocking of the Oriental trade routes by the Turks, still they must have been so to some extent. And, in certain respects therefore, the invasion of America by the Europeans must be considered as a result of the invasion of Europe by the Turks.

The lost Atlantis also must have helped to arouse the curiosity of medieval seamen. For the account given in Plato that a great island or continent had been destroyed in past millenniums was certainly known in the Middle Ages. Atlantis was then supposed to be in the Atlantic Ocean, whose name not impossibly is connected with that of the island, and some early navigators may easily have had it in mind in searching for new lands or islands. It was indeed not until A.D. 1909, that a real foundation for the Atlantean tale was offered, when some thoughtful person suggested in an anonymous letter to an English newspaper that the lost Atlantis of Plato was Minoan Crete. And certainly Plato's story answers in many respects to Minoan Crete and its destruction as revealed by archeology, and in an article "Atlantis or Minoan Crete,"<sup>2</sup> I tried to explain Plato's narrative by comparing it with Minoan Cretan and Greek history and mythology. One point, however, namely the statement that the sea around Atlantis had become unnavigable, remained very dim. About this, Mr. William H. Babcock, the author of numerous scholarly and important papers about the discovery of America, in a letter to me, suggested that this might refer to the Sargasso Sea, and this certainly seems like a plausible explana-

<sup>2</sup> *The Geographical Review*, May, 1917.



tion. For if it is true that Phœnician coins have been found on one of the Azores, it is possible that some knowledge of the Sargasso Sea may have filtered into Egypt and become mixed up with the destruction of Minoan Crete. But although the story of Atlantis is so confused and so jumbled out of discordant elements that we may never feel quite sure of them all, yet as far as the discovery of America is concerned, we must remember that the belief that there had been such an island in the Atlantic and that it was close to other lands, may well have urged on some of the early Atlantic navigators.

Among the impelling causes of Portuguese discovery also, must be reckoned one man. This was the Portuguese Prince, known as Henry the Navigator. He was the son of John I., King of Portugal, and his wife Philippa, daughter of John of Gaunt, Duke of Lancaster, and was thus half English. Born in 1394, he died in 1460, and devoted most of his life to fathering voyages of discovery. Some English writers laud him to the skies as the finest flower of chivalry, but one Portuguese writer at least claims that he was a brutal bigot and slave driver. Leaving his moral character to the tender mercies of others, history records that in June, 1415, Henry the Navigator took part in a predatory attack on the town of Ceuta, Morocco, which was wrested *vi et armis* from the Moors. Apparently his sojourn with the Moors inspired him with a desire to explore the African coast of the Atlantic Ocean and after his return to Portugal in 1418, he settled on the promontory of Sagres, Portugal, a name corrupted from its name *Sacrum* of Roman days, and built an observatory and some houses there. Here he spent most of his life, studying geography, interviewing seamen and preparing expeditions of discovery. In certain respects, the settlement of Sagres might be considered the first geographical society of the world. And although Henry the Navigator did not himself make any voyages of discovery and although none of the voyages which he fathered made known to the world the existence of the American continent, still his work aroused the interest and opened the way which eventually led to the successful voyage of Columbus. Indeed there is probably no individual who did as much to bring about the European invasion of America as Henry the Navigator.

Many of the early voyages of Portuguese or Spaniards were either unrecorded or else the records were destroyed and lost. Proof of this is shown by the fact that constantly the Portuguese and Spanish libraries and private archives yield documents revealing totally unknown circumstances. As an instance of this may be cited the case of one whole district of the island of Madeira which is called Machico, and that this was the name of a Portuguese sailor of 1379 is shown by a unique document found only in 1894.<sup>3</sup> Of one early voyage, however, the strange invasion or conquest of the Canary Islands by the Sieur Jean de Béthencourt, a Norman French nobleman, in 1402-1405, we have an elaborate account, one copy of which in the Bibliothèque Nationale of Paris is illuminated like a missal with old drawings. But although the written records are scanty, there is no doubt that during the fifteenth century many commercial ventures and voyages of exploration into the Atlantic were made, not only by Portuguese and Spaniards, but also by Englishmen. Cape Bojador was rounded by Gil Eanes in 1435, Cape Verde in 1445 and between then and 1448 it is said that more than thirty ships sailed round it. Long voyages into the Atlantic are recorded in 1452, 1457, 1460, 1462, 1473, 1475, 1476, 1480-81, 1484, 1486. Some of these went at least 150 leagues to the west; one of them discovered or rediscovered the Sargasso Sea; all of them were in search of lands or islands in which the belief seems to have been very general. There are some rough written records of some of these voyages and they tell very fairly the evolution of discovery down the western coast of Africa.

The best records of discoveries in the western Atlantic in the fourteenth and fifteenth centuries, however, are maps. For as I have said earlier in this article, the evidence of maps is exceedingly hard to controvert. When land or sea is charted with some accuracy, even if there is no message in words about the matter, the chance is that a discovery had been made. And on these early maps of the Atlantic, the factor of especial importance in regard to America are the islands and their names.

Some names of islands persist with striking tenacity on these

<sup>3</sup> Batalha-Reis, *The Geographical Journal*, February, 1897.



early maps. One of these names is Brazil or Brazir, which is claimed to be Irish, either a compound of the Irish Gaelic words "breas" and "ail" or to be descended from the Irish Saint Bresal. It is applied both to a small island not far west of Cape Saint Vincent, Portugal, and also to an island and sometimes to two islands in the same longitude not far west of Ireland. This northern Brazir is found on Dulcert's map of 1339, on the Catalan Atlas of 1375, etc. On the Pizigani map of 1367, there are three islands of Brazir in about the same longitude, and one of them is placed in the latitude of Brittany with two ships in distress flying the Breton flag near it. Mr. William H. Babcock,<sup>4</sup> the best living authority on the subject, has suggested that this island is intended to represent Newfoundland and possibly was discovered by the Irish, and before 1367 reached also by some Breton sailors. There is one objection to this theory, however, and that is the longitude of the islands of Brazir. The northern island or islands are not far from Ireland. If any mariner had genuinely reached Newfoundland before 1367, it would seem as if he would have reported it as an island far away from Ireland. There is of course no island in the charted position, and if the latitude is correct it could be only Newfoundland. And it must be recognized that even though the longitude is incorrect yet that the latitude and the bigness of the island are decided evidence in favor of Brazir being Newfoundland. While the theory must be considered as non proven, still the evidence is sufficiently strong to prevent it from being lightly thrown aside.

There is one island or group of islands which is especially noteworthy, Antillia, from which we have made the Antilles. Some writers have sought to derive the name from Atlantis, but Mr. William H. Babcock has shown that the proper derivation comes from Anti-Ilha or Ante-Ilha, meaning the island in front of, that is to the west of the others. Originally Antillia seems to have been considered as an island to which many Portuguese are reported to have fled as a refuge when the Arabs invaded the Iberian peninsula in the beginning of the eighth century. At least there is a legend

<sup>4</sup>"Indications of visits of White Men to America before Columbus," Proc. Nineteenth International Congress of Americanists, Washington, 1915.

to this effect on Martin Behaim's globe of 1492, on which it is also stated that a Spanish ship visited Antillia in 1414. In the fourteenth century the name Antillia was applied to the most westerly of the Azores. In the fifteenth century, however, several cartographers, Andrea Bianco in 1436 among others, drew maps which jump Antillia far, far to the west of the Azores. It is figured as a great big island, in about the latitude of Portugal; with another big island, Salvagio or Satanaxio, to the north of it. The main extension of Antillia and Satanaxio is about north and south, their latitude is somewheres between Florida and Massachusetts, and considering their distance beyond the Azores, their longitude would coincide roughly with the eastern coast of the United States.

Although the matter is hazy and there is no verbal evidence beyond the few words on Behaim's globe, yet the cartographical evidence shows positively that map makers of the fifteenth century had a distinct belief in big lands far west of the Azores, in about the latitude and longitude of the eastern coast of the United States. Several of these maps certainly point to extensive coasts way beyond the Azores having been reached before 1435. The name Antillia would validate rather than invalidate the reality of such a discovery. And where there is so much smoke it seems as if there must be some fire. A visit to the Antilles or to the coast of the United States before 1435 seems much less improbable than that map-makers should have correctly guessed the existence of big land masses so far to the west, which in their extension north and south and in their latitude and longitude, so closely approximate to the eastern coast of the United States. Personally I am strongly inclined to believe in the genuineness of this discovery, which may perchance have been made by the Spanish ship whereof Behaim speaks.

The most interesting and important pre-Columbian map of the Atlantic, however, without question is the Venetian cartographer Andrea Bianco's map of 1448. The problems presented by this map were broached by Dr. Yule Oldham<sup>6</sup> and were admirably de-

<sup>6</sup> *The Geographical Journal*, March, 1895.

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veloped by Senor Batalha-Reis.<sup>6</sup> Here I wish to merely recapitulate briefly the chief arguments of these scholars.

Andrea Bianco's map is on vellum 86 centimeters by 63 centimeters. It is now in the Ambrosian Library at Milan and its authenticity is generally accepted. It is one of the *portolani*, that is one of the maps made by seaman for seamen for practical purposes and free from the fanciful geographical conceptions and fabulous zoölogical monstrosities of the maps drawn by convent monks. The map takes in France, Spain and the African coast down to Cape Verde, and, as far as known, is the first record of the coast line of Cape Verde.

The remarkable feature of the map, however, is that at the extreme lower left hand corner is represented an extensive coast line southwest of Cape Verde. On this an inscription in the old Venetian dialect seems to read: "ixola otinticha xe longa a ponente 1500 mia," which may be translated: "Authentic island distant to the south west 1500 miles." The position of the coast line and the legend together seem to show that somebody, before the year 1448, had seen a land southwest of Cape Verde and some 1,500 miles distant. But there is no island in this position, while at 1,520 miles southwest of Cape Verde is the northeast promontory of South America.

There is no known account recording any voyage making such a discovery, therefore it is well to see whether there is any indirect evidence that such a discovery might have been made. In the first place there were a great number of voyages in search of lands during the fifteenth century. Then we must remember moreover that some of these voyages were not recorded and were sometimes entirely forgotten. It is, therefore, perfectly possible that such a discovery may have been made and left unrecorded if, for instance, it was made by some merchant vessel or fishing boat blown out to sea. Indeed this very thing happened in this very place in the year 1500, when Cabral's expedition, en route for India round the Cape of Good Hope, was blown out to sea and strayed over in a casual

<sup>6</sup> "The Supposed Discovery of South America before 1448 and the Critical Methods of Historians of Geographical Discovery," *The Geographical Journal*, February, 1897.

sort of way to Brazil. That such a discovery was not followed up before 1492 would be simply because no one at that time could have any idea of what such a discovery meant. The land would have been looked on as another island and one too far away to be of much use.

On Martin Behaim's globe of 1492, there is a large island in the position of part of the coast of South America, in fact in the exact position given by the legend on Biancho's map of 1448.

The Treaty of Tordesillas of 1494 insured to Portugal all the eastern part of South America. Why this treaty should have been ratified unless the Portuguese already had knowledge of these lands it is hard to see. Spain claimed the lands discovered by Columbus and Portugal claimed the lands to the south probably reported by Portuguese navigators.

On the 1st of May, A. D. 1500, Master Joao, physician to D. Manuel of Portugal, wrote to the King about the land (Brazil) just found by the fleet of Cabral on board of which he was, "that those lands might the King see represented on the mappamundi which Pero Vaz Bisagudo had." He adds that the mappamundi does not mention if the land were inhabited, while he could certify it to be well peopled. He also says that the said mappamundi was ancient. This last statement is strong evidence that somebody must have seen the land before 1492.

Las Casas, writing between 1552 and 1561 about the third voyage of Columbus in 1498, says that Columbus wanted to go south because he believed he could find lands and islands, and also because he wanted to see what King D. Joao of Portugal meant when he said that there was "terra firma" to the south. The grounds for the belief of Columbus have never been explained.

The map itself and the side evidence do not make this landfall a certainty. But they certainly make it a probability. Personally the weight of evidence seems to me to lean very decidedly in favor of South America having been reached by some unknown Portuguese navigator half a century before Columbus reached American shores.

The first southern European voyage to America, however, of



which we have absolute definite historic record, is, of course, the first voyage of Columbus. This voyage it was which made known generally to Medieval Europe the existence of lands of great extent far away to the west in the Atlantic. And although the Irish reached Iceland and the Norsemen Greenland and some points of the American coast, and although some Portuguese or Spaniards probably also did the latter before Columbus, yet, to the world of Europe, Columbus was the man who kindled the torch which dispelled the darkness enwrapping the West, and in this matter at least, the popular verdict of history is correct in calling Columbus the discoverer of America. But, although we have records of his four great voyages, although we know much about Columbus, yet of many things connected with Columbus we are still ignorant.

Among the things we do not know with any certainty is why Columbus came to start on his journey. There has been much talk that he corresponded with an Italian philosopher named Toscanelli, who is said to have proved to him that by sailing westward he would find the coast of Asia. Some have claimed that a study of Marco Polo was the influencing motive of Columbus. There is a story that he met on some isle near the African coast a pilot who died in his arms and who assured him that he had sailed far across the Atlantic to distant shores. There is another tale which shows Columbus arriving at Iceland and thus hearing of the lands, already nearly forgotten in Europe, which had been the goal of the Northmen several centuries before. None of this, however, is in any respect authenticated: none of it indeed rises much beyond the status of a legend. What we do know, however, is that Columbus had the spark of exploration fever burning brightly in his heart and that it spurred him on for years until he finally won the greatest prize in the history of discovery.

Again, who actually sighted first an American land on Columbus' first voyage? Was it Columbus or one of his companions? And on what day did this happen? It is usually assumed that Columbus himself made the landfall on the 12th of October, 1492. But there is no certainty of this. The records of the voyage show that Columbus himself claimed sighting land before dawn on October 12,

but one of his sailors, Rodriguez of Tryana, put in a claim that he had seen the land in the early morning before Columbus; and another sailor on Pinzon's ship, Juan Rodriguez Bermejo, there-upon put in a claim that he had seen a sand beach reflecting the moonlight in the evening of October 11. It also happens that as the old calendar was still in use, the correct dates according to our present chronology should be some ten days later, either October 20 or October 21. And there the matter stands! We know neither who it was of Columbus's expedition who first sighted an American shore, nor do we know exactly on what day this took place. And this perforce must always remain a mystery, as the data are insufficient to clear it up.

Perhaps the queerest adjunct of Columbus's great discovery, however, is the fact that Columbus himself never knew that he had discovered a continent. Columbus till his dying breath believed that he had reached outlying parts of India. And there is one proof of this which can not be gainsaid and that is that he called the copper-colored natives whom he met Indians. To this day, we keep on repeating this error and call the original inhabitants of our continent Indians, with the result that sometimes it is hard to distinguish as to whether we are speaking of the natives of America or of the swarthy races of Hindustan. But it does seem hard that Columbus should have revealed to Europeans the existence of the vast territory extending from Bradley Land to Tierra del Fuego and yet have gone to his rest believing he had been on the shores of Hindustan.

But the very ignorance of Columbus in regard to the American continent is evidence in favor of earlier discoverers. The early maps always show islands. No one dreamed of a new continent. A mariner sighted a coast and told of it and the map-makers charted it as an island. Maps before Columbus indicated numerous islands in the western ocean corresponding roughly with parts of America. It certainly seems far more likely that these islands were based on some foundation of genuine exploration and of actual perception by early mariners than that they should have been invented correctly in cartographic workshops in Europe. Especially probable



does this seem, when one remembers that for some years after parts of the continent had been visited and portions of its coast had been charted, the explorers themselves still believed that they had merely revealed the existence of some big islands belonging to the land mass of Asia.

Mysteries thicken rather than lessen after Columbus had gone around the turning point in American discovery. The explorer who first announced that there were lands, continental in size, in the west, apparently was Amerigo Vespucci. He did so in several little tracts which are tangled up and hard to unravel, but whose publication in his lifetime tended to make him better known than other more silent explorers. It was in his letter to Lorenzo di Pierfrancesco di Medici especially that he spoke of the new world he had visited on the caravels of the King of Portugal. He also said that the land which they—that is the expedition of which he was a member—had discovered, seemed to them, not an island, but a continent. Furthermore he mentioned that they had sighted land 90 degrees of latitude distant from Lisbon—referring almost certainly to South Georgia in 52° south latitude whilst Lisbon is in 38° north latitude—and thus had measured the fourth part of the globe.

Martin Waldseemüller, an armchair geographer residing at Saint Dié in the Vosges mountains, became impressed with these statements of Amerigo. In 1507 he published a booklet in which he suggested that since Amerigo had discovered a *Novus Mundus* or fourth part of the world, therefore it should be called after him. With the book, he brought out a world map, on which he placed the name America on the lands south of the Equator visited by Amerigo.<sup>7</sup> Undoubtedly he took an exaggerated view of Amerigo's reports. He passed over Columbus and Amerigo's even now unknown commander and looked on Amerigo as the discoverer of this New World. But barring this error he located the name America correctly on his map on what is now Brazil.

There is no evidence that Amerigo ever heard of the name America. Nevertheless because of it he has been abused like a pick-

<sup>7</sup> Basil H. Soulsby, "The First Map Containing the Name America," *The Geographical Journal*, Vol. XIX., Feb., 1902.

pocket and has been accused of stealing the glory which should belong to Columbus. But all the evidence shows Amerigo guiltless of aught except of being a member of several important voyages of exploration and of writing somewhat hazily about them. And equally, barring the error in regard to Amerigo's commander, there was every reason why Waldseemüller should name the new land America. For remember he did not impinge on the discoveries of Columbus: he applied the name America only to the coast of Brazil, where it should still be. It was only years after all the actors in the matter were dead, that the name gradually became attached to the entire continent. Having myself named the two halves of the Antarctic Continent, West Antarctica and East Antarctica, and also some parts of it such as Charcot Land and Nordenskjöld Land, personally I have the deepest fellow feeling for Waldseemüller.

Occasionally some mystery is cleared up. For instance, in 1894 entirely private documents were discovered showing that Joao Fernandes Lavrador was one of the commanders of one or more expeditions sent to discover lands to the northwest of Europe between 1491 and 1496. This was probably the origin, formerly unknown, of the name of the part of North America which we call Labrador.\*

More often, mysteries are not cleared up. For instance the map of Juan de la Cosa of 1500 shows a coast line extending from Newfoundland to Florida which must be the coast of the United States. The maps of Cantino and of Canerio of 1502 show the southern part of the coast between Florida and about New York, then a blank, then Newfoundland. Apparently two navigators had explored the coast roughly before 1502 but who were they? John Cabot possibly was the first and Amerigo is sometimes guessed to be the second culprit. But no one knows!

There are some curious mysteries connected with Magellan's voyage. One is the statement of Antonio Pigafetta that when Magellan's expedition arrived at the north of the straits so well named after him: "all the men were so assured that these straits had no opening to the west, that no one would have thought of

\* Batalha-Reis, *The Geographical Journal*, February, 1897.



seeking it, except for the great knowledge of the Captain-general [Magellan]. This man, as clever as he was brave, knew that one must pass through a strait very hidden, but which he had seen marked on a map made by Martin Behaim, a most excellent cosmographer, which the King of Portugal kept in his treasury." The other strange occurrence is that the same year that Magellan sailed through the straits, Johannes Schöner made his famous globe, now in Nuremberg, showing South America much in its real shape, although extending only to 40 degrees south latitude. Pigafetta's statement and Schöner's map are not satisfactorily explained as yet. Perhaps they never will be!

One more unexplained cartographical mystery and I have done. Straits under the name of Fretum Anian appear as a water separation between Asia and America on Zaltieri's chart of the year 1566, almost exactly in the position of Bering Straits explored by Vitus Bering in 1728. And from 1566 on they hold their own on charts and atlases, varying their location a little each time until after the year 1700. If one looks at one of these old charts it is hard to believe that some one had not explored Bering Straits before 1566. And yet not only is there no record of any such voyage, but all the evidence which there is goes to show that there was no such voyage.<sup>9</sup> The only solution of this mystery would seem to be native reports of these straits filtering through to the Chinese and being communicated by them to some early European traveler. But there is no record of anything of the kind. Nevertheless although the known evidence seems to prove that Bering was the first to sail through Bering Straits, the fact remains that more than a century and a half before Bering, some cartographer appears to have found out that wide straits separated the Asiatic and American continents.

There are many other unexplained occurrences connected with the evolution of American discovery which are not touched on in this paper. But this paper is not an attempt to give a complete history of the subject. It is rather an attempt to get at the philosophy of the matter; of the causes which led to the discovery;

<sup>9</sup> F. A. Golder, "Russian Expansion on the Pacific," 1914.

of its long, slow and gradual development; and of our lack of knowledge about any number of its incidents. And I hope I have carried out my main purpose, which is to show that the discovery of America is not in the least the single occurrence it is popularly supposed to be, but that it is an evolution, and an evolution tinged throughout with mystery.



## TATAR MATERIAL IN OLD RUSSIAN.

By J. DYNELEY PRINCE.

(Read April 25, 1919.)

It seems to have been a characteristic of Russia from the earliest times until the present moment to take a morbid pleasure in her own failures. Whatever one may think in general of Stephen Graham's<sup>1</sup> opinions regarding Russia, he was certainly correct in emphasizing the prevalence of what may be termed the gospel of incompetency among the Russians of to-day. Public sympathy has been at all times in Russian history with the unsuccessful, rather than with the triumphant hero, and nowhere is this disconcerting trait more cogently evident than in some of the literature of the old Russian period, best exemplified by the "Epic of Igor," or, more fully, the "Tale of the Armament of Igor" (1185 A.D.).<sup>2</sup> This poem relates in grandiloquent style, often verging upon that of a Scandinavian Saga, the defeat of the ancient Russian Prince Igorj<sup>3</sup> Svjatoslâvič by the well-disciplined Tatar hordes of the Pólovtsy in southern Russia. The epic abounds with words and other traces of the influence of this and perhaps of other Tatar civilizations, a fact which is all the more interesting, because this literature antedates by about two generations the advent of the Golden Horde under the succes-

<sup>1</sup> Stephen Graham, "The Way of Martha and the Way of Mary," London, 1915.

<sup>2</sup> The name Igor (*Igorj*) like so many other princely names of this period is pure Norse (= Ingvar); cf. Rjurik = Hrörekr; Truvor = Thorvardr; Oleg = Helgi; Rogvolod = Rognvaldr, etc. For the poem, cf. L. A. Magnus, "The Tale of the Armament of Igor," Oxford, 1915.

<sup>3</sup> The phonetic system of transcription in the present article is essentially the Serbo-Croatian. Note, however, that the apostrophe is used to denote the Russian hard sign = stop or short vowel (*Schwund*) and that the *j* after a consonant = palatalization (Russian soft sign). The Russian vowel *yery* (= *i* in English *lid*) is represented by *y*. As regards the abbreviations, C. = Cumanian; CC. = "Codex Cumanicus"; OR. = Old Russian; OS. = Old Slavonic, and R. = Russian; ZDMG. = *Zeitschrift der Deutschen Morgenländischen Gesellschaft*.

sors of Jenghis Khan. These rulers held the Russians in well organized tributary thralldom for nearly two centuries (from 1223 A.D.).

As attention to the Oriental material in Russian has been called quite recently, perhaps for the first time in English, by Mr. Magnus, I have in the present paper ventured to advance some of my own views as to this subject and to emphasize the points regarding which I am at variance with the work of that scholar, as well as to set forth some of the facts now established with tolerable certainty concerning this early period of Slavo-Turkic intercourse. The information herein gathered is not intended to be exhaustive and may be supplemented on the lexicographical side from such works as Berneker's "Slavisch-Etymologisches Wörterbuch" and Radloff's "Wörterbuch der Türk-Dialekte."

The first question confronting the student of this Tatar<sup>4</sup> influence in Igor is that of the identity of the Pólovtsy, who appear throughout the Epic as the successful and often not unchivalrous foes of the adventurous hero and his company.

We have direct and convincing evidence in the Chronicle of Nestor (1096) as follows: "And Ismael begat twelve sons, whence come the Turks, Pečenegs<sup>5</sup> (White Huns), Torks (remnants of the Pečenegs) and Kumans, that is to say the Pólovtsy who 'came out of the desert.'" In other words, the Turkic tribes known to us as Cumanians were identical with the Pólovtsy. It is highly probable that the word *Kuman* is a popular etymology from *qum*, "sand," indicating that these tribes originated in the sandy steppe; i. e., "came out of the desert," but that the original of the word was *Kun* = Hun.

Our chief source of information as to the idiom of these Kumans

<sup>4</sup> Tatar is a name generally applied to all Turkic, Mongolian and Hunnic tribes; in short, to every Oriental non-Russian people in the former Russian Empire. See below, note 9. Turkish of practically every variety is more or less intelligible in essentials to all the Turkic tribes. Hunnic (Finno-Ugric), however, differs very much in its various dialects.

<sup>5</sup> The Pečenegs, or White Huns, were also called *Bissen*, *Byssen*, Παῖσιναι in Arabic *Badžak*, etc. Cf. Anna Comnena, Bonn Ed. p. 404): *πρόσκειται τοῖς καμάνοις ὡς ὁμογλώσσους* "they are very close linguistically to the Cumanians."



or Cumanians is the "Codex Cumanicus,"<sup>6</sup> edited by the Hungarian Count Geza Kuun, and, in spite of many errors, a most valuable record of the speech of the Cumanians, giving a sketch of the grammar, word-lists, and texts with late Latin-Persian-Cumanian in the first part, and Cumanian-Old-German in the second part.<sup>7</sup> Besides this, mention should be made of the brief "Interpreter of the Language of the Pólovtsy," found in a Russian manuscript of the sixteenth century,<sup>8</sup> which gives a small number of so-called Pólovtsian words with Russian translation. As to the term "Pólovtsy" itself, it would seem to be a cognate with the race-term "Palocz," found in the Hungarian Chronicle, used interchangeably with Kun = Hun = Kuman.<sup>9</sup> In the Chronicle of Nestor, the word Pólovtsy was

<sup>6</sup> Comes Geza Kuun, "Codex Cumanicus Bibliothecae ad Templum Divi Venetiarum," Budapest, 1880; "Additamenta ad Codicem Cumanicum, Nova Series," Budapest, 1883; W. Radloff, "Das türkische Sprachmaterial des Codex Cumanicus," St. Petersburg, 1887 (*Académie Impériale des Sciences*), criticized by W. Bang in the following works: "Beiträge zur Erklärung des Komanischen Hymnus," in *Nachrichten der kön. Ges. der Wissensch. zu Göttingen, philologisch-historische Klasse*, 1910, pp. 61-78; "Über einen komanischen Kommunionshymnus," in *Académie royale de Belgique*, Bruxelles, 1910, pp. 1-12; "Zur Kritik des Codex Cumanicus, Librairie universitaire des trois rois," Louvain, 1910, pp. 1-17; "Beiträge zur Kritik des Codex Cumanicus," in *Académie royale de Belgique*, Bruxelles, 1911, pp. 13-40.

<sup>7</sup> As Bang has pointed out ("Beiträge," pp. 32 ff.), the first part of the "Codex" was probably written by Italians and the second half by Germans, both parts having been composed under Franciscan influence, as is evident from the prominence accorded to St. Francis. The scope of the work was undoubtedly missionary and not commercial, as the chief stress in the vocabulary and texts is laid on religious material. The "Codex" in both parts belonged to the library of the poet Petrarch, 1350-1370. Before that date, the documents were in the possession of one Antonius de Finale ("Codex," p. 218). Both parts were probably brought from the Black Sea missions to Italy, where the manuscript was compiled and edited by Genoese and Venetians. It seems clear that this "Codex" had nothing to do with the Cumanians settled in Hungary, who kept their idiom as late as 1744.

<sup>8</sup> P. K. Simoni in *Proceedings of the Department of the Russian Language and Literature of the Imperial Academy of Sciences*, 8, 179-191; 185-197, St. Petersburg, 1909.

<sup>9</sup> See Friedrich Hirth, "Die historisch-geographischen Beweise der Hiung-nu = Hun Identität," Budapest, 1910, and cf. also his "Ancient History of China," pp. 31-35, New York, 1908.

plainly associated with Slavonic *polje*, "field"; hence "desert," but *polje* is a soft noun and would have produced the derivative *póljevec* and never *pólovec*.

A brief examination of the material found in the "Interpreter" mentioned above and a comparison with the Cumanian of the Codex and with modern Osmanli will satisfy the most cursory reader as to the true Turkic character of the Cumanian-Pólovtsy language.

POLOVTSIAN INTERPRETER.	CUMANIAN.	OSMANLI.	
<i>ten̄gri</i> <sup>10</sup>	<i>tengri</i>	<i>tan̄gri</i>	"God"
<i>kok</i>	<i>kok</i>	<i>kjök</i> ( <i>gjök</i> )	"heaven"
<i>kujas̄</i>	<i>kujas̄</i>	<i>güneš</i>	"sun"
(probably error for <i>kunjas̄</i> )			
<i>iludus</i> <sup>11</sup>	<i>julduš</i>	<i>jildiz</i>	"star"
<i>aan</i>	<i>ay</i>	<i>ay</i>	"moon, month"
<i>kar</i>	<i>kar</i>	<i>k(j)ar</i>	"snow"
<i>amgur</i>	<i>yamgur</i>	<i>jaghmur</i>	"rain"
<i>suuk</i>	<i>suk, saok, saogh</i>	<i>soúk</i> ( <i>soghúk</i> )	"cold"
<i>isi</i> <sup>12</sup>	<i>isi</i> hot	<i>yšyq</i>	"light" ( <i>sydšak</i> hot)
		<i>ekmek</i> (original)	
<i>etmen̄k</i>	<i>etmac</i>	<i>etmek</i> )	"bread"

The grammatical structure of the Cumanian was also strikingly similar to that of Sart and Osmanli, as may be noted from the following few examples of the pronouns, nouns and tenses of the verb:

<sup>10</sup> In the "Interpreter," the first vowel is the 39th letter of the OS. alphabet, often wrongly transcribed *ja* in Russian. Its real value was a nasal *e*, as in *eng* (= Polish nasal *e*), but the vowel frequently corresponds to Russian *ja*.

For a similar comparison between Cumanian and Tatar, see the work cited above note 8, and note the incorrect vocalization in *tjagri*, *op. cit.*, p. 191. This universal Turkish word is very probably connected with the ancient Sumerian *dingir* "God" (soft form *dimmer*); cf. Prince, Materials for a Sumerian Lexicon, p. viii, Leipzig, 1909.

<sup>11</sup> Scribal error for *julduš* = *julduš*.

<sup>12</sup> Written *aan*; evidently scribal error for *aai*.

<sup>13</sup> *Isi* = *yšy*, with obscure vowel *y*; not *iš* (Radloff, *op. cit.*, p. 120). Radloff's readings of the *Codex* are not always trustworthy.



## PRONOUNS.

CUMANIAN.	SART.	OSMANLI.	
<i>men; man</i>	<i>mān</i>	<i>ben</i>	"I"
<i>mening</i>	<i>mening</i>	<i>benim</i>	"of me"
<i>manga; man ga</i>	<i>manga</i>	<i>bana (baŋga)</i>	"to me"
<i>meni; menj</i>	<i>meni</i>	<i>beni</i>	"me" (acc.)
<i>mendan</i>	<i>mendin</i>	<i>benden</i>	"from me"
<i>biz</i>	<i>biz</i>	<i>biz</i>	"we"
<i>bizing</i>	<i>bizing</i>	<i>bizim</i>	"of us"
<i>bizga</i>	<i>bizga</i>	<i>bize</i>	"to us"
<i>bizni</i>	<i>bizni</i>	<i>bizi</i>	"us" (acc.)
<i>bizdan</i>	<i>bizdin</i>	<i>bizden</i>	"from us"

CUMANIAN.	SART.	OSMANLI.	
<i>sen; san</i>	<i>sān</i>	<i>sen</i>	"thou"
<i>sening</i>	<i>sening</i>	<i>senin</i>	"of thee"
<i>sanga</i>	<i>sanga</i>	<i>sana</i>	
<i>(saha; saa)</i>		<i>(saŋga)</i>	"to thee"
<i>seni</i>	<i>seni</i>	<i>seni</i>	"thee" (acc.)
<i>sendan</i>	<i>sendin</i>	<i>senden</i>	"from thee"
<i>siz</i>	<i>siz</i>	<i>siz</i>	"you"
<i>sizing</i>	<i>sizing</i>	<i>sizin</i>	"of you"
<i>sizga</i>	<i>sizga</i>	<i>size</i>	"to you"
<i>sizni; siznj</i>	<i>sizni</i>	<i>sizi</i>	"you" (acc.)
<i>sizdan</i>	<i>sizdin</i>	<i>sizden</i>	"from you"

## NOUN.

CUMANIAN.	SART.	OSMANLI.	
<i>su</i>	<i>su</i>	<i>su</i>	"water"
<i>suning</i>	<i>suning</i>	<i>sunyn</i>	"of water"
<i>suga</i>	<i>suga</i>	<i>suja</i>	"to water"
<i>sunī</i>	<i>sunī</i>	<i>suju</i>	(acc.)
<i>sudan</i>	<i>sudin</i>	<i>sudan</i>	"from water"
CUMANIAN.	SART.	OSMANLI.	
<i>sular</i>	<i>sular</i>	<i>sular</i>	"waters"
<i>sularning</i>	<i>sularning</i>	<i>sularnyn</i>	"of waters"
<i>sularga</i>	<i>sularga</i>	<i>sulara</i>	"to waters"
<i>sularni</i>	<i>sularni</i>	<i>sulary</i>	(acc.)
<i>sulardan</i>	<i>sulardin</i>	<i>sulardan</i>	"from waters"

## VERB.

## PRESENT TENSE.

CUMANIAN.	SART.	OSMANLI.	
<i>anglarman</i>	<i>anglamen</i>	<i>anglarym</i>	"I understand"
<i>anglarsen</i>	<i>anglasen</i>	<i>anglarsen</i>	"thou —"
<i>anglar</i>	<i>angladur</i>	<i>anglar</i>	"he —"
<i>anglarbiz</i>	<i>anglamiz</i>	<i>anglaryz</i>	"we —"
<i>anglarsiz; -sis</i>	<i>anglasiz</i>	<i>anglarsynyž</i>	"you —"
<i>anglarlar</i>	<i>angladurlar</i>	<i>anglarlar</i>	"they —"

## PRESENT TENSE NEGATIVE

<i>anglarman</i>	<i>anglamaimān</i> (-men)	<i>anglamam</i>	"I do not under-stand"
<i>anglarmasen</i>	<i>anglamaisen</i>	<i>anglamassen</i>	"thou —"
<i>anglamas</i>	<i>anglamaidur</i>	<i>anglamaz</i>	"he —"
<i>anglamasbiz</i>	<i>anglamaimiz</i>	<i>anglamajyz</i>	"we —"
<i>anglamassiz</i>	<i>anglamaibiz</i>	<i>anglamassynyž</i>	"you —"
<i>anglamaslar</i>	<i>anglamaidurlar</i>	<i>anglamazlar</i>	"they —"

## FUTURE.

<i>anglagaymen</i>	<i>anglarman</i>	<i>anglajadžaghym</i>	"I shall under-stand"
<i>anglagaysen</i>	<i>anglarsen</i>	<i>anglajadžagsyn</i>	"thou —"
<i>anglagay</i>	<i>anglar</i>	<i>anglajadžaq</i>	"he —"
<i>anglagaybiz</i>	<i>anglarmiz</i>	<i>anglajadžaghys</i>	"we —"
<i>anglagaysiz</i>	<i>anglarsiz</i>	<i>anglajadžagsynyž</i>	"you —"
<i>anglagaylar</i>	<i>anglarlar</i>	<i>anglajadžaqlar</i>	"they —"

As will be observed, the Sart Tatar of Eastern Russia is even more similar to Cumanian than is Osmanli, as the *m*-form of the pronoun of the first person *man-men* constantly appears instead of the Osmanli *ben*. The inserted *n* before the nominal-pronominal genitive-ending *-ing* (*-yn*), which remains in Osmanli only in words ending in a vowel, is still common in Sart, as it was in Cumanian.

In 1338 A.D., the Franciscan Friar Pascal of Vittoria wrote that he learned the *lingua Chamanica* and the Uigur letters, "which are used commonly throughout these kingdoms;" that is, throughout the empires of the Tatars, Persians, Chaldæans, Medes and Cathay.<sup>14</sup> In other words, Pascal states that Cumanian was the idiom in common use as a vernacular throughout Central Asia as far as China

<sup>14</sup> Cited Bang, *Beiträge*, p. 33.



and that it was written with Uigur characters. Cumanian was evidently a term applicable to Tatar in general, including Uigur.<sup>15</sup> There can be no doubt that the material of the "Codex Cumanicus" is of great value, therefore, in fixing the philological status of all præ-mediæval and mediæval Tatar and especially of the Pólovtsian idiom, with which it was practically identical.

I am particularly indebted to Mr. Feliciu Vexler, Assistant in Slavonic in my Department in Columbia University, for his able assistance in collecting most of the following Tatar material, bearing directly on the language of the Epic of Igor.

#### TATAR MATERIAL IN IGOR,<sup>16</sup>

*Bľvan* (Igor 112) = modern R. *bolvan*, "block, blockhead, statue, idol" (Berneker, p. 41), C. *balaban*, "falcon," possibly owing to the statue-like attitude of the bird when perched. In Magyar, *bálvány* = "idol of any sort"; Rumanian *bolovan*, "cobble-stone," formerly "idol" (Slavonic loanword). There may be two words here, the first referring to a bird of some sort; cf. Turkish *bülbül*, "nightingale" (in CC. *rosignolus*); and the second actually meaning "block" or "idol." The word is clearly of Tatar origin.

*Bojan* (Igor, *passim*). For full discussion, cf. "Prince, Trojan and Boyan," in Proc. of the Amer. Philos. Soc., 56, 152-160 and see below, *s. v. kur*. Vyazemski (Magnus, p. xlvii-xlvi) has already connected this word with Salvonic *bajati*, *bojati* "speak, relate." The meaning of *bojan* may therefore, be "singer"; cf. R. Gypsy *bagan*,<sup>17</sup> "to sing," and note Slav. *bajan*, "enchanter," in Dan. 5, 11 (OR. version). It is possible, however, that the word may be of Tatar origin (cf. Magnus, p. xlvii). Note that Turkish *boj* = "person"; Mongol *boj* = "clever archer" or "person"; Altai *pajana* = "God"; Čuvaš *pojan* = "rich" and *bajan* is a tribal name of the Altai. See below, *s. v. bojarin*. The word *bajan* appears also as a proper name, *Vajanos* (but note the Greek *v*), son of Kubra. Dubious words of this type are often the result of a compound

<sup>15</sup> Cited Bang, *Beiträge*, p. 33.

<sup>16</sup> Arranged in the order of the Russian alphabet.

<sup>17</sup> Cf. P. Istomin (Patkanoff), "The Gypsy Language (in Russian)," Moscow, 1900.

derivation, possibly originally Tatar with a superimposition of a later Slavonic folks-etymology, based on resemblance of sound (see *s. v. buj-tur, jar-tur*, below).

*Bojarin* (Igor, *passim*); the common OS. word for "magnate" (Berneker, p. 72), usually employed for Slavonic *boj*, "fight," following the idea that the boyars were essentially warriors. It may however be connected as a loan-word with the above mentioned Turkish *baj*-, *boj*- "rich," since the probably cognate R. *barin*, "gentleman" does not seem to be from a Slavonic stem *boj*-, "fight." The words *barin*, *bojarin*, therefore, are possibly Tatar. In OS. and Bulgarian, *boljarin*, the *l* is probably due to the influence of the Slavonic *bolj*-, "great." See the Tatar material cited above, *s. v. Bojan*.

*Buj-tur* (Igor, 80) varies with *buj* (Berneker, p. 98) and is an epithet of Prince Vsevolod. Here again is a word of possible double etymology. The Slavonic elements appear to be *buj*, "bull," and *tur*, also "bull," meaning "aurochs" in modern R. A similar popular combination is *buj-vol*, "buffalo," from *buj*, "bull" and *vol*, "ox."

The *buj*-form is apparently cognate with Greek, *φύω* "to sprout, be born"; cf. Rumanian *buia*, "lustful." The word *buj* alone appears in Igor, 465; *Buj Rjuriče* "O hero (bull) Rurik"; the genitive is *bu-j-ego*. This *buj*-element can have no connection with *C. boga*, *buga*, Turkish *bugha*, Cagatai *buka*, etc.

All through the Tatar idioms we find variants of the word *bahadur*, "noble, mighty," now a common word in Hindustani dialects borrowed through the Mogul (Mongol); cf. *C. bahadur*, Mongol *batur*, Manchu *baturu*, Nogait *matur*, beautiful, Kazanj *mater*, etc.

Note CC. 145: *bahadur sen degelim*, "te potentem esse dicamus"; CC. 116: *bagat* = "probus." In spite of Magnus, Igor, p. 51, I believe that *buj-tur* is a Slavonic popular etymology from Tatar *bahadur*, or its cognate; cf. *s. v. jar-tur*, below.

*Bus*: *busovi vrani* "the crows of Bus" (Igor, 375), altered by Magnus from *bosuvi*, but better = "steel gray crows," a variety common in Russia to-day. Magnus, Igor, p. 50, associates it with



Booz=Bluz (Baluš), a leader of the Pólovsty in 1054, during the first invasion; cf. *pojút vrémja búsovo*, "they sing the times of Bus" (in this passage, plainly a proper name). The word *búsovi* (Igor, 375) is more likely connected with *bosy* (Igor, 685): *bósym vólkom*, "like a gray wolf," not "bare-footed" and hence "swift-footed" (Magnus). For the idea of color, see *C. buz*="caeruleus" (CC. 145); note also *boxag* (= *bozag*) "*fuscus*" and cf. Turkish *bos*, "steel-gray," and Osmanli *buz*, "ice." These Slavonic expressions are all certainly loan-words from Tatar *buz*, "blue; gray."

*Bjes*: *djěti bjěsovi* (Igor, 186); translated by Magnus "children of Baal," i. e., "devilish children" (cf. Berneker, p. 56). Magnus thinks *bjes* is a variant of *bus*-, but this is probably incorrect, although it suggests the Cummanian *bus*, *bos*, seen in *busov*="ruina" (CC. 195). The phrase *bjěsovi djěti* must mean "children of the devil," from the Slavonic stem *bjes* (*běs*) "rage."

*Ženčjug*, "a collection of pearls" (Igor, 371); an older form than the present *žemčug*. Prof. Friedrich Hirth states that this is an international word, known also in China; cf. Lithuanian loan-word *žemczugas*. This same stem is seen in Magyar *gyöngy* and in Osmanli *inčü*, pronounced *indži*. Note that the change of *j* or *i* to the palatalized *dž* is not unusual in Turkish; cf. *C. ingčü* (CC. 109), Orkhonski Tatar *jänčü*, etc. This word does not appear in the non-Russian Slavonic languages.

*Kaninu* (Igor, 225): *na Kaninu zelenu papolomu polstla* "and bedded in him in the Kanina with a garment"; thus Magnus. Note that *papoloma*=Greek *πέπλωμα*. Magnus, p. 74, rejects a Tatar derivation, but *C. kan* and Turkish *kan*="blood." This word *kanina* is probably a hybrid adjective meaning "bloody" and the phrase should be translated: "and bedded him on a blood-stained green garment"; viz., in the earth. I question as to whether Kanina in Igor is a place-name=Kajala; cf. 229: *s toj-že kajaly* ought probably to be read: *s toj-že kaniny* "from that place of blood." The hero's father-in-law ordered his body to be carried to Kiev.

*Kogan* (Igor, 746): *na kogana* "against the Khan"=Tatar *kaghan* (Orkhonski inscriptions; cf. Berneker, 468). This title

was given to Vladimir in Chron. 1171: *kagan* and *kan* in 1191. The gutturalized *khan* is a later form; Greek *χάγης*; *χαγάνος*, old Mongol and Avar *khaganus* (-us=Latin ending), Osmanli *khan* and C. *han*—"God." In Cumanian the *h* represented a guttural. The Tunguz of Nerčinsk say *kan* with hard *k*.

*Koščej* (Igor, 360): *v. sjedlo koščievo* "in a captive's saddle" (not "slave's," with Magnus). Cf. Berneker 585. The word is clearly a Tatar element from *koš*, "military camp," from which comes R. *koš*, "camp of the Zaporozhian<sup>18</sup> Cossacks"; hence, the word used so often in Gogol's "Tarás Búlba," *koshevoj*—"chief of the Cossack camp." The word *koščĭ* must originally have meant "prisoner, servant, groom." There can be no connection here with C. *cuč* and *cučermen*, "coerce," as some have suggested. In the R. ballads *koščej* meant "magician, giant." It is possible that the modern R. *koščej*, "skinflint, miser" may be the same word misapplied under the popular etymological influence of *kostj*, "bone." The stem *koš* may be the same as that seen in Osmanli *qawas* (?)

*Komonj*, "horse" (Igor, *passim*) is probably not a Tatar word. It has been connected with a supposed *kobmonj*, the same stem as that seen in R. *kobyła* and English-Celtic "cob"=thick-set horse (*cob* in Celtic="tuft, abundance"), but Berneker, 555, rightly rejects this as a doubtful derivation. The usual R. word for "horse" is *lôšadj*, *q. v.*, below.

*Kur* (Igor, 595): *doriskaše do kur Tjmutarakanja*. There is no reason to alter to *čur* with Magnus—"he raced to the precincts of Tjmutarakanj." Magnus's emendation would refer to Čur, a deity (?) of boundaries. The word *kur* is Tatar *qur*, "enclosure," with which *kurgan* (see the following word) is probably connected.

*Kurgan* "tumulus, grave-mound," a common modern R. word (Berneker, 648) appears also in Rumanian *gorgan* and is clearly Tatar. Note C. *gurgan*, "burgh" and *gurgatmen*, "strengthen," and cf. Osmanli *kurkhane*. See the preceding word in this list.

*Lôšadj*, "horse" (not in Igor, which always uses *komónj*, *q. v.*). The word *lôšadj* (Berneker 734) appears in *Nestor's Chronicle*, 1103

<sup>18</sup> The Zaporozhian Cossacks were the "Backfallsmen" of the Dnieper who played so important a part in Polish mediæval history (cf. Gogol's Taras Búlba, etc.).



and 1111, used by Vladimír Monomákh in the council regarding the Polovtsian expedition. The term was unknown to the Pólovtsy and was of southern Russian origin, passing into Russian, perhaps, by way of the Viatici tribe (cf. Šakhmatov, *Introd. to the History of the Russian Language*, I. 81). The word appears in OR. as *loša*; gen. *lošáte* (*t*-stem) and has had the form *lōšadj* since the thirteenth century; cf. *lošák*, "mule," Pol. *lossak*, "horse," etc. It is unquestionably a Tatar loan-word; cf. Turkish *alâşa*, "gelding," and Magyar *lo*, "horse."

There were wild horses on the Asiatic steppes, as Vladimír Monomákh speaks of catching and taming ten or twenty of them at Cernígov.

*Nogata* (Igor, 460): *to byla by čaga po nogatje a koščěj po rézanje*: "then a female slave would be worth twelve pence and a groom for five pence."

This is a loan-word through the Tatar from the Arabic *naqd*, "small coin." The intermediate form seems to have been *nagd*. For the values in furs, one *grivjenj*=twenty *nogaty*, or fifty *rezany*, see Magnus, p. 113. See below *s. v. čaga*.

*Ovlur* (Igor, 675) is a proper name; probably the same as *Lavor* in Nestor's Chron. 1185. This appears to contain the same elements as are seen in the Turkish *oghlan*, "servant, lad"; we have the record in Nestor of the Tatar servants of David Igorevič, named Oulan, Kolča, etc. The form *Lavor* is certainly not as correct as *Ovlur*. The final *r* in both forms is difficult to explain, unless it is a variant of the *-n* in *oghlan*, *oulan*.

*Oljber* (Igor, 101) is clearly not Tatar ölybyr, "weak, ill" (rejected also by Magnus, p. 102). Magnus is probably right in attributing this name to the series of geographical terms referring to the Tatar territory, now in Czecho-Slovakia. Note that there is a Polish village Olbierzowice, not far from Warsaw (Magnus, *loc. cit.*). Vexler derives this from Pol. *olbrzym*, "giant," applied to the Avars. Cf. *s. v. šeljbir*.

*Or'tama* (Igor, 142; only once): *or'tmami i japončicami kožukhi*, "with the mantles, cloaks and coats" (they bridged the mire, etc.). This is plainly the same as C. *ortma*—"mantica"; cf. *art*, "back,

top" (CC. 146), *artarmen*, "I excel" (CC. 54). In Osmanli, *örtmek* = "to cover," and we find in Persian the noun *örtme*, "covering" from a plainly Turkish formation which, however, does not occur in modern Osmanli. This is undoubtedly our *or'tma* = Osmanli *ürtü*, "covering."

*Saltany* (Igor, 489): "thou shootest from the golden throne of thy father the Saltany who are beyond Russia" (= *za zemljami*). Every authority but Magnus regards this as the Arabo-Tatar *salṭān*, *sulṭān*, a reference to the chiefs of the Tatars. Magnus, however, considers, that it alludes to the men of Salatyn on the lower Tatra mountains in Hungary, whence came the barbarian auxiliaries of Igor, such as the Topchaks. It must refer to an attack on the Tatar foe, but the term *salṭān* (*sulṭān*) is not commonly used to denote the Tatar khans.

*Tl'kovin* (Igor, 369): *paganykh tl'kovin*, "of the heathen *tl'koviny*"; perhaps the *Ταμάρις* of Ptolemy. The term is very difficult. It is usually rendered "nomads," from R. *tolčák*, from *tolkútj*, "roam," as the form occurs in Nestor, 907, alluding to the Varjags, Slovenes and Tivercy. A. Weseloffsky (ZDMG, 1877, p. 301) refers the term to the Torki, the remnants of the Pečenegs. This is not possible, since the Varjags (Norsemen) and Slovenes (southern Slavs) were certainly not Torki. The derivation of the word *tl'koviny* is uncertain. The proper pronunciation is *tlkoviny* or *tolkoviny*, as the hard sign in Igor *tl'koviny* is a mere stop. Šakhmatov thinks it means "bi-lingual," comparing it with *tolmač* "interpreter," from *tolkováti* (*op. cit.*, p. 98).

*Tjmutarakan* (Igor, 384) was the last outpost of the Russo-Hellenic influence and had heathen temples even in Strabo's day. It was on the Tamán peninsula, bordering on the Sea of Azóv and the Black Sea. Constantine Prophyrogenitus calls it *Ταμάραχα*.

*Topčak* (Igor, 432) alludes to the barbarian allies. Magnus states "this word has an unmistakable Turanian form" and refers to C. *toprak*, "corn" (CC. 208). In Osmanli *topraq* = "soil, territory," and also "clay." It may refer to the nature of the soil of a certain territory. Magnus identifies it geographically with Topczewo, a village in the province of Grodno, twenty versts from



Bielsk, or with Topczykaly, seven miles from Grodno. There can be little doubt that these people were Tatars.

*Šeljbyry* (Igor, 432) may be cognate with Kalmuck *šilbyr*, "long whip," but the term seems to accord with the rest of the geographical series; cf. *s. v. Oljber*, and Magnus, p. 101. It is probably another reference to the barbarian allies of the Russians from the Tatra. Note that Pol. *szalbierz* means "rogue."

*Šereširy* (Igor, 462; only once):

<i>ty by možeši po sukhu</i>	Thou canst on dry land
<i>(živymi) s šereširy streljati</i>	shoot with bold šereširy
<i>udalymi<sup>19</sup> syny Gljebovi</i>	the sons of Gljeb.

The sons of Gljeb were princes of Rjazanj. The passage is very obscure and it is apparent that the copyist himself did not understand it. Cf. Magnus, pp. 106 ff., for seven views. I believe that *šereširy* must have been an implement. The Persian fire-hurling machines were known as *tir-čar*, an iron pipe filled with explosive powder and employed very early in the East. Magnus, p. 107, suggests that *šerešir* may be cognate with Magyar *seres*, "worry, trouble," but this seems improbable. Vexler suggests that the initial *š* may be a scribal error for *t*, as the letters are not dissimilar in Cyrillic, but this is not necessary, as a *t* palatalized before the *i*-vowel might become *s*. The word *šereširy* suggests a Pólovtsian word *čiričar* and seems in this passage of Igor to be a synonym of the *plamenny rog* "flaming horn," of Igor, 312; note also *smaga*, "fierce heat" (Igor, 311), a Little-Russian word. "Live *šereširy*" must mean "loaded implements."

*Kharalužny* (Igor, 194): *méči kharalúžnymi*, "with steel swords" (Berneker, 385; 100) is undoubtedly connected with C. *karalic*, "blackness," used for *atramentum*, "ink," in CC. 94, but referring in Igor to the dark color of tempered steel. It is interesting to note that in modern Osmanli, *qaršilyq* is used for the steel of a flint-lock gun, but this really means "the opposite thing," *i. e.*, the thing opposite (*qarši*) the flint." On the other hand, *qaršilyq* may

<sup>19</sup> It is not necessary with Magnus to separate *-mi* from *udaly* and to regard *mi* as the 1st personal possessive "my brave sons of Gljeb"; *udalymi* is instrumental plural agreeing with *šereširy*.

be a popular etymology containing an original *qara*-stem—"black steel (?)." Perhaps *qaršilyq* stands for *qar-čelik*, "black steel," as *čelik*—"steel" in Osmanli. In the Russian ballads, *bulatny* means the same as *kharalušny*—Turkish *bulat*, which is from Persian *pulad*; thus, in *Zadonščina*; *kopija kharalušnymi, meči bulatnyja, topory legkie*, "steel spears, steel swords (and) light battle-axes." Note that *k* and *q* often become *kh*, especially in Azerbaijan and Mariópol Tatar (cf. Blau, "Ueber Volksthüm u. Sprache d. Kumanen," ZDMC. 29, 1876 [556-567], pp. 569 f.

*Khinovy* (Igor, 403). This original form Magnus has needlessly altered to *khinju*; *khinovy* is probably an adjective and means simply "Hunnish" (thus Sobolevsky, A. S. P., xxx, p. 474). It is derived by Magnus from Tatar *khan* and taken to mean "belonging to the Tatars" (*khans*), a theory based on the change of *o* to *i* in Little Russian, seen, for example, in Little Russian *pid* for R. *pod*, "under"; *wikno* for *oknó*, "window," etc. But this change of *o* to *i* is a very late phenomenon in the Ukraine. It is not likely that this word has any connection with C. *kinov*, "crooked" (CC. 138), *kingir*, "curved" (CC. 140).

*Khorjúgov* (Igor, 146); cf. Berneker, 398. This word has been derived from Mongol *oroŋgo* "standard" and also from Gothic *hrugga* "shaft," pronounced *hrunga*, which is not even identical in meaning. The word occurs in Old Bulgarian *khorangv*, "pennant" and in modern *khorúgv*, "church banner," Pol. *choragiew*, etc. It is more probable that this is a Tartar loan-word and not Gothic *hrugga* which is the same word as English "rung" of a ladder. The Mongol *oroŋgo* may be a modification of an original *khoronggo*.

*Japončica* (Igor, 142) "Capuchin cloak" (Berneker, p. 445). Magnus has wrongly *japoncica* (p. 115). This is identical with OR. *epanča* and Turkish *iapanča*, or *iaponča*; in Polish *oponczka* means "rain-coat." Note Cagatai *japonči* "cloak." See *s. v. or'tma*, below.

*Jaruga* (Igor, 92) "rill" (Berneker, 445) is clearly the same as in Čagatai *jarugh*, "left, split." The *jar*-stem appears in OR. *jar*, "cliff, ravine"; Old Bulgarian *jar* "steep shore," Rumanian *eruga*. In modern R., we have *jarug* (Tula dialect), and *eruk*; *jaruška* Little-Russian.



*Jar-tur* (Igor, 190; Magnus, p. 117; Berneker, 447). This is an epithet applied to heroes; conventionally="fierce bull." See *buj-tur*, above. There is a modern word *jary* "fierce, grim," which probably does not belong in this connection. As *buj-tur* seems to be a popular etymology of Slavonic elements suggested by a primitive Tatar form, it is highly likely that the same is true of *Jar-tur*, with which the Indo-Germanic elements *jar*, "fierce" and *tur*, "bull" have been associated. Note that R. *jary* appears in a number of Slavonic proper names, as *Jarosláv*; *Jaromir*, etc.

This Indo-Germanic *jar* is usually connected with Greek ζῆλος, "fiery"; possibly it has the same stem as the Latin *ira* "wrath" (?). According to Berneker, p. 448, this *jar* has no connection with the Tatar *iar*, "light, bright," which occurs CC. 254. The question is confusing, as *jary*, "bright" is also a Slavonic stem, R., etc. It is conceivable that *jar-tur* might readily be a variant of Tatar *iardur*, "he is (*dur*) splendid," a form which subsequently might have been confounded with Slavonic *jary* (?).

As to the possible connection between Slavonic *jary* and Tatar *iar* (*iariklich*="lumen," CC. 154; *jaricte*, "illuminavit," CC. 159; *iarkin*, "splendor," CC. 193), this opens up the whole question as to the primitive common origin of the Indo-Germanic and Ugro-Turkic idioms which cannot be discussed here.

*Čaga* (Igor, 460) "female slave" (Nestor, Chron. 1018) is undoubtedly Tatar and should not be rendered "potentate" (Magnus, p. 113). See above *s. v. nogate*.

## THE ENERGY LOSS OF YOUNG WOMEN DURING THE MUSCULAR ACTIVITY OF LIGHT HOUSEHOLD WORK.

BY FRANCIS G. BENEDICT AND ALICE JOHNSON.

*(Read April 24, 1919.)*

In the computation of the food requirements of women and children, certain factors have been applied to the standards for men—factors which have long been established and which are based solely upon differences in body-weight. Since the body-weight of the average woman is but 80 per cent. of the body-weight of the average man, it has been assumed that the food requirements of women are in like proportion. The average energy requirement of the resting woman has been found to be actually 17 per cent. less than that of the average man under the same conditions of muscular repose. Furthermore, studies in the Nutrition Laboratory upon the differences in the need for energy of quiet men and women have shown that with complete muscular repose and absence of food in the stomach, men on an average produce 6.2 per cent. more heat than women of the same age, height, and weight.

But food requirements are made up of two factors: (*a*) the food required for the maintenance of the quiet body doing no external work; (*b*) the excess food needed for the accomplishment of the various daily tasks. Dietary allotments, therefore, deal not only with the basal requirements but also with the very considerable excess food required for the multitudinous daily tasks. The variety of mechanical operations and muscular movements incidental thereto which are engaged in by men is very great; ultimately the energy requirements for these different operations should be established. It is popularly considered that the muscular activity of the average woman is much less than that of the average man. This is probably true, but as household work in some form or other still remains a



not inconsiderable factor in the muscular activity of most women, exact information as to the energy needs for the performance of the domestic duties of the household is essential for an intelligent computation of the daily requirements of the average woman. These domestic activities consist for the most part of sitting, standing, walking, sewing, sweeping, dusting, washing clothes and dishes, ironing, cooking, bed making, etc. What, then, are the requirements for energy above the basal for these and other activities?

The Nutrition Laboratory, in establishing its long series of basal values for new-born infants, children, and adults, has adhered to the time-consuming method of studying *individuals*, and a decade has been needed to secure this basal information. In the belief that with definitely established basal values, the excess energy required for muscular activity could be studied to greater advantage with groups, and thus *general average* values be obtained more rapidly and possibly with a greater degree of accuracy, a respiration chamber of sufficient size to seat 30 to 40 persons was constructed and its accuracy tested.<sup>1</sup>

This respiration chamber, 5.18 meters long, 3.81 meters wide, and 2.29 meters high, is well ventilated by forcing outdoor air in at one end and withdrawing the chamber air at the other. The special feature of this apparatus is the sampling device. A rotary air impeller discharges air from the chamber into a copper box or wind chest having three circular openings in it, two of these being 10 millimeters in diameter and one 29 millimeters in diameter. The amount of air leaving the wind chest through these three openings is roughly proportional to the area of each opening and is obviously alike for the 10-millimeter openings. Over each of these two openings is placed a can covered with a rubber bathing cap to enclose the discharged air. By means of a supplementary blower, air is withdrawn from each of the sampling cans at exactly the rate at which it is delivered into the can. In actual practice, therefore, the air enters the cans at atmospheric pressure, is immediately withdrawn, forced through containers holding sulphuric acid and soda lime, respectively, and then discharged. By weighing the soda-lime con-

<sup>1</sup> For a detailed description of this chamber, see Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, pp. 92 to 119, inclusive.

tainer, the carbon dioxide absorbed from the air passing through the 10-millimeter openings may be quantitatively determined.

The exact proportion of air passing through the 10-millimeter openings was found by admitting a known weight of carbon dioxide to the chamber from a steel bottle of the liquefied gas, and determining the amount of this gas which passed through each opening. In the present apparatus this happens to be exactly 10 per cent. of the total, *i. e.*, 10 per cent. of the air is delivered through each of the 10-millimeter openings and 80 per cent. through the 29-millimeter aperture. The weight of carbon dioxide absorbed in the purifying vessel, corrected for the amount of carbon dioxide contained in the incoming air (a correction obtained by a simple calculation), is therefore exactly one tenth of the total amount produced in the chamber during the experiment, provided no change has taken place in the percentage of carbon dioxide residual in the chamber air. Analyses of the residual air, made with a Haldane apparatus at the beginning and end of the period, give this correction, and the true carbon-dioxide production is thus rapidly determined.

With this respiration chamber, experiments with periods no longer than twenty minutes are perfectly practicable. The determination of the carbon-dioxide production has of itself but little value, but is used for computing the heat production by means of the calorific value of carbon dioxide at an assumed respiratory quotient. Such a method is admittedly not so accurate as the direct measurement of the heat production, or the computation of the heat production from measurements of the oxygen consumption. It is, however, a rapid method and not too costly for determining the approximate heat output of a group of people.

Through the personal interest of Professor Alice F. Blood, several groups of Simmons College undergraduates were interested in the research and volunteered to act as subjects for this series of experiments. The studies were made with over two hundred women. In this research the standard values used for comparison were not obtained under the usual experimental conditions for determining basal metabolism, that is, twelve hours after the last meal and with the subject lying down in complete muscular repose, but to



give practical living conditions, they were determined two hours after a very light breakfast and with the degree of repose possible with the subjects sitting quietly, reading. Hence, this standard value or base line should not be confused with true basal minimum metabolism measurements. From past experience, the standard value here used may be estimated to be not far from 10 per cent. higher than the true basal or minimum value.

All of our experiments were made with one or more periods at the beginning, in which the standard value was established for the day under the conditions outlined. Observations were then made of the increment due to reading aloud, singing, sewing, standing quietly, sweeping, dusting, standing up and immediately sitting down, and with the subjects marching in single file around the chamber. These observations are now being extended so as to include many more household activities. The ages, heights, and body-weights of all of the subjects have been recorded. The calculations of the metabolism have been made on the basis of uniform body-weight, as Harris<sup>2</sup> has recently shown that the metabolism per kilogram of body-weight is, with homogeneous material, a satisfactory method of comparison.

Since every experiment contained periods in which the standard metabolism was determined for use as a basal value, a considerable amount of data is available showing the metabolism of the subjects while they were sitting quietly, reading. The results of these quiet periods are given in Table I. as heat output per kilogram of body-weight per hour. In computing these values, we have assumed a respiratory quotient of 0.90, since all of the experiments were made two hours after a light breakfast. The calorific value of carbon dioxide at this respiratory quotient has therefore been used in all of our calculations, namely, 2.785 calories per gram of carbon dioxide. From this series of experiments on twelve different days, embodying twenty-three periods, in which over two hundred women participated, it is seen that the average heat production per kilogram per hour was 1.12 calories. This average figure of 1.12 calories has a specific interest in that it indicates the probable heat production of

<sup>2</sup> Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 160.

women sitting quietly under ordinary living conditions with a moderate amount of food in the stomach.

TABLE I.  
RESTING METABOLISM OF GROUPS OF YOUNG WOMEN.  
(Subjects sitting quietly reading, 2 hours after light breakfast.)

Date.	Number of Women.	Number of Periods.	Heat Output per Kgm. per Hour.
1917			cal.
January 15.....	20	1	1.16
20.....	14	1	1.07
April 7.....	15	1	1.05
14.....	15	1	1.12
21.....	23	3	1.12
			1.06
			1.05
23.....	18	3	1.11
			1.10
			1.15
30.....	20	2	1.13
			1.06
			1.07
May 5.....	19	2	1.23
			1.12
1918			
March 16.....	25	3	1.20
			1.21
			1.18
April 6.....	25	2	1.18
			1.21
April 27.....	15	1	1.13
May 4.....	15	2	1.00
			0.97
Average.....	—	—	1.12

The percentage increments in the metabolism due to the various household activities studied are given in Table II. These are arranged in the order of increment in energy requirement. Although perhaps of minor practical importance, it is of physiological interest to note the metabolism necessary for reading aloud. In these experiments the students read in unison either from a standard college text book or from the book of Psalms. Three experiments with twenty-three to twenty-five women, with a total of eight periods, showed increases of 3, 1, and 5 per cent., respectively, with an average of 3 per cent. Frankly, this was rather a surpris-



ing observation, for it would be expected that the effort of reading aloud would be measurably greater than here indicated.

The slight increase in metabolism due to reading aloud is of even greater interest when compared to the large increments noted when the subjects were singing. In these experiments the subjects sang from a book of college songs or a standard hymnal used in chapel. In the three experiments with fourteen to twenty women, covering in all four periods, the rather irregular percentages of 17, 34, and 16 were obtained, with an average of 22 per cent., this being

TABLE II.  
PERCENTAGE INCREASE IN METABOLISM OF WOMEN DUE TO LIGHT MUSCULAR ACTIVITY.

Occupation.	Number of Women.	Number of Experiments.	Number of Periods.	Increment.	
				In Individual Experiments.	Average.
Reading aloud . . . . .	23 to 25	3	8	p. ct. 3	3
				1	
Standing quietly . . . . .	20	1	1	5	9
				9	
Hemming . . . . .	15	2	2	16	13
				10	
Singing . . . . .	14 to 20	3	4	17	22
				34	
Dusting . . . . .	15 to 19	3	4	16	134
				126	
Sweeping . . . . .	15	2	4	121	150
				156	
				139	
				161	

more than seven times greater than that noted when the subjects were reading aloud.

To determine the increment in the metabolism due to the labor of plain sewing (hemming), two experiments with fifteen women, and covering two periods, gave 16 and 10 per cent., respectively, with an average of 13 per cent. Since in this sitting occupation, the bodies of the subjects remained relatively quiet and the arms alone were moved, it is perhaps not surprising that the increment was no greater.

To throw some light upon the additional energy requirements necessary for maintaining the standing position, one experiment with twenty women with one period was made in which it was found that the extra metabolism required for standing was 9 per cent. above the standard sitting resting metabolism. This agrees reasonably well with values found in this laboratory for subjects in the post-absorptive condition for the differences between sitting and standing.

As a typical household occupation, involving moderate muscular exercise, the metabolism during sweeping was studied in two experiments with fifteen women and covering in all four periods. The increments noted were 139 and 161 per cent., respectively, with an average of 150 per cent. This is somewhat less than the increase due to moderate walking found in the Nutrition Laboratory, which was approximately 250 per cent. above the metabolism with the subjects in the standing position.

Another household occupation studied, involving rather moderate muscular effort, was that of dusting. In these experiments the subjects were required to dust chairs, wiping the rounds and seat, and at a given signal change to the next chair in rotation. One minute was allowed for dusting each chair. Three experiments with four periods with fifteen and nineteen women gave increments above the basal value of 126, 121, and 156 per cent., respectively, with an average of 134 per cent., an increase only slightly less than that noted in the sweeping experiments, namely, 150 per cent.

The increment in energy with two other muscular activities was studied in this series of experiments but the results are not included in Table II. The muscular work of standing up and sitting down enters into a relatively large number of the daily activities and a special study of this operation was made in that the subjects while sitting quietly in a chair were, on a given signal, required to stand up, remain standing one second, and then immediately seat themselves. This routine was carried out approximately once every minute during the period. In this particular series, it seemed best to compute the increments not as a percentage above basal but as the actual increase in energy for standing up and sitting down per move-



ment and per individual. Two experiments with eighteen and twenty women, covering a total of three periods, gave values of 0.31 and 0.32 calorie, respectively, averaging 0.32 calorie. It thus appears that with young women an energy expenditure of approximately one third calorie is required for the activity of standing up and sitting down.

On one date, April 6, 1918, a group of twenty-five young women marched slowly about the respiration chamber for twenty-five minutes. The distance walked in going around the chamber once was forty-five feet; this was accomplished about fifty-three times in twenty-five minutes, the exact total distance walked being 2,356 feet. On that particular day the standard value found and used for the base line was 1.20 calories per kilogram per hour. During the walking the heat output was 2.44 calories per kilogram per hour, or an increment over the standard value of 1.24 calories per kilogram per hour. The rate of walking was 1.08 miles an hour and the average weight of the subjects fifty-four kilograms, from which it is readily computed that at this very slow rate of walking the energy above basal required for transporting the body was sixty-two calories per mile. While very few of the experiments on walking made in the Nutrition Laboratory employed so slow a rate of walking as this, many of our observations with slightly faster rates give values from 40 to 60 calories per mile although usually with men, with consequently somewhat higher body-weights. Too little evidence is thus available to indicate whether or not walking at so slow a rate is performed on a distinctly uneconomical basis. The value is not far from that commonly quoted from German sources for the energy required in walking one mile at a moderate rate.

The method used in this research seems to be well founded and applicable to such study. An extension of these observations is planned to include not only women and children, but also men engaged in various activities, these studies forming a part of the general study of muscular work now in progress at the Nutrition Laboratory.

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BOSTON.

# ALTERNATING-CURRENT PLANEVECTOR POTENTIOMETER MEASUREMENTS AT TELEPHONIC FREQUENCIES.

BY A. E. KENNELLY AND EDDY VELANDER.

(Read April 26, 1919.)

## HISTORY OF THE APPARATUS.

The measurements presented in this paper have been made in the electrical engineering laboratories of the Massachusetts Institute of Technology, with a new form of a.-c. planevector potentiometer, giving its potential readings in rectangular coördinates. This instrument lends itself readily to the measurement of vector potential differences up to frequencies of at least 2,000~. The principle of the potentiometer is the same as that described by Professor Larsen<sup>1</sup> in 1910; but the present form of the instrument has been worked out in the M. I. T. laboratories, mainly through the thesis studies of Mr. A. E. Hanson.<sup>2</sup>

The essential connections of the instrument and its method of application are outlined in Fig. 1. The anti-inductive resistance  $ab$  is connected in series with the primary winding  $bc$ , of a toroidal non-ferrie induction coil included in the main potentiometer circuit  $P$ . The secondary winding  $bd$ , of the induction coil, is connected at  $b$  with the junction of the primary coil and the resistance. The secondary winding of the induction coil, and the resistance  $ab$ , are both provided with suitable taps, which are brought out to dials, for adjustment of the potential connections at  $k$  and  $l$ . When a sinusoidal alternating current  $I_p$  r.m.s. amperes  $\angle$ , from the oscillator source  $O$ , at a suitable impressed frequency, passes through the potentiometer circuit, the alternating p.d. between the taps  $k$  and  $l$  will be

$$E_p = I_p(R + jX), \quad \text{r.m.s. volts } \angle \quad (1)$$

where  $R$  is the resistance included between  $k$  and  $b$  in ohms, while

<sup>1</sup> Bibliography 9.

<sup>2</sup> Bibliography 13.



$jX = jM\omega$  is the mutual reactance included between  $l$  and  $b$ .  $M$  denotes the mutual inductance between the primary winding and the part  $bl$  of the secondary, and  $\omega = 2\pi f$ , is the angular velocity (in

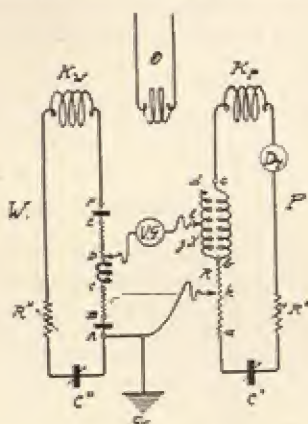


FIG. 1. Simplified diagram of connections, showing the rectangular potentiometer  $P$  arranged for exploration of the potential distribution over the working circuit  $W$ .

radians per second) of the impressed frequency  $f$ , in cycles per second.

The oscillator also supplies current to an associated working circuit  $W$ , containing the apparatus in which the distribution of plane-vector<sup>a</sup> a-c. potential is to be explored. A tuned vibration galvanometer,  $VG$ , enables a potential balance to be obtained between a selected pair of terminals on the working circuit, and the adjustable taps on the potentiometer circuit, so as to secure the relation

$$U_{AB} = I_p(R + jX), \quad \text{r.m.s. volts } \angle \quad (2)$$

whereby the p.d. at the terminals, say  $A$  and  $B$ , can be evaluated in terms of the calibrated constants  $R$  and  $X$  of the instrument, and the measured potentiometer current  $I_p$ , taken at standard phase. If, however, another p.d., say  $U_{BC}$ , for instance, across a standard re-

<sup>a</sup>A planevector may be defined as a geometrically directed complex quantity in a plane of reference, and subject to the laws of complex arithmetic, as distinguished from a vector which is subject to the laws of vector arithmetic. In this paper the term "vector" is used as an abbreviation of "planevector."

sistance  $r$  ohms, as indicated at  $BC$ , in Fig. 1, is measured immediately after  $U_{AB}$ , we have

$$U_{BC} = I_p(R_0 + jX_0), \quad \text{r.m.s. volts } \angle \quad (3)$$

Then

$$\frac{U_{AB}}{U_{BC}} = \frac{R + jX}{R_0 + jX_0} \quad \text{numeric } \angle \quad (4)$$

In this way, the relative numerical values of the p.d.'s on different parts of the working circuit can be evaluated, preferably in terms of the p.d. on a standard resistance, without requiring a measurement of the potentiometer current  $I_p$ .

As thus far described, the instrument can only measure vector p.d.'s confined to a single quadrant. By means of reversing switches, however, on  $X$  and on the entire potentiometer, all four quadrants in the voltage complex plane can be explored.

A more detailed description of the instrument, and of its mode of operation, technique and limitations, appears in a paper by the writers published\* elsewhere; so that only a brief outline of this part of the subject will here be necessary, in order to present more fully in this paper some of the results which have been secured with the instrument, at telephonic frequencies, in the laboratory.

#### SIMPLE SERIES CIRCUIT OF RESISTANCE, INDUCTANCE AND CAPACITANCE, AT CONSTANT FREQUENCY AND VARIED CAPACITANCE.

In Fig. 2 the connections are shown of a simple working circuit containing an inductance  $L$  of 0.8106 henry, a total resistance  $R$  of 3183 ohms, and an adjustable condenser  $C$ . Such a circuit may briefly be described as a  $RLC$  circuit. The connections  $pp'$  to the potentiometer are also indicated. The inductance  $L$  was very loosely coupled with the Vreeland oscillator  $Osc$ , and the oscillator frequency was maintained at 500~.

With the condenser  $C$  shorted; *i.e.*, made infinite, the potentiometer reading on 100 ohms in  $r$  was the vector  $OA$ , as obtained from rectangular coördinates in  $R$  and  $-jX$ , viz.  $-22.5 - j176$  millivolts. This is indicated as a vector of 179.4 millivolts, at a slope

\* Bibliography 14.



of  $-97^{\circ}.2$  with respect to the reference axis  $OR$ , which coincides with the phase of the current  $I_p$  in the potentiometer circuit.

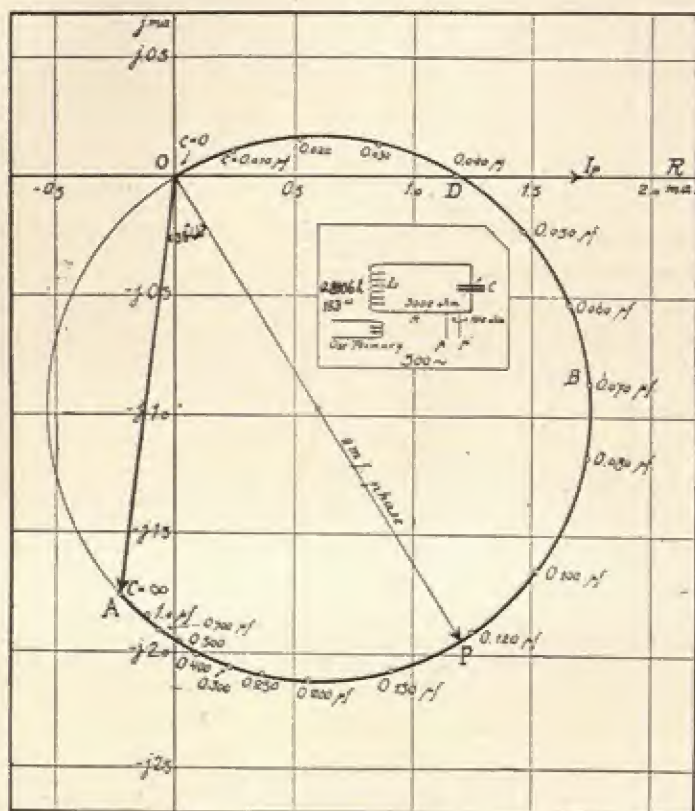


FIG. 2. Current locus, under constant impressed e.m.f. of 500~, of a simple circuit containing inductance, resistance, and capacitance, the latter being varied from  $0.03 \mu f$ . to  $\infty$ .

As the capacitance in the condenser  $C$  was reduced, the vector voltages at the terminals  $pp'$  advanced along the locus  $APBDO$ , which is seen to be a circle passing through the origin of coördinates  $R$  and  $jX$ .

It is easy to demonstrate that a circular locus must apply to the current and therefore to the potential difference at  $pp'$ . The im-

pedance in the working circuit of Fig. 2 is

$$Z = R + j \left( L\omega - \frac{1}{C\omega} \right) \quad \text{ohms } \angle \quad (5)$$

If we keep  $r$ ,  $L$  and  $\omega$  constant, but vary  $C$ , the impedance will advance vectorially along a straight line parallel to the  $j$  axis, or reactance axis. This is shown in Fig. 3, where distances along the horizontal real axis represent values of resistance  $R$ ; while distances along the  $j$  axis represent values of reactance. As the value of  $C$

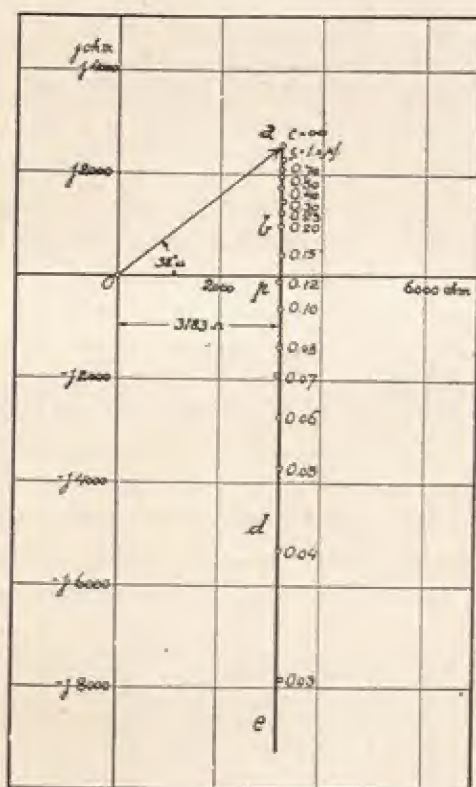


FIG. 3. Planevector impedance locus of a simple  $RLC$  circuit in which the capacitance is varied.

was changed from infinity to  $0.03 \times 10^{-6}$  farad, the vector value of impedance moves along the straight line  $a b d e$ . The impedance  $Z$



therefore pursues a straight-line locus. The current in the working circuit will be

$$I_w = \frac{|E_w| \angle \beta^0}{Z} \quad \text{amperes } \angle \quad (6)$$

where  $|E_w|$  is the constant size of the induced e.m.f. in that circuit, and  $\beta^0$  is the angle of lag of that e.m.f. behind the current in the potentiometer circuit, considered as of reference phase. This circuit happened, in this case, to be strongly condensive, owing to the adjustment of the condenser  $C'$  in Fig. 1. The angle of lag  $\beta$  is the angle  $DOP$  in Fig. 2. In equation (6) the vector impedance  $Z$  appears as a reciprocal, or in the denominator. It is well known that the reciprocal of any vector straight-line locus is a circular locus passing through the origin. The diameter of the circle through the origin is also the reciprocal of the perpendicular distance from the impedance origin to the impedance locus. Consequently, in Fig. 2, with  $|E_w| = 7.273$  volts, the diameter  $OP$ , expressed in amperes, will be  $7.273 \times 1/3181 = 0.002285$  ampere, or 2.285 milliamperes, lagging  $\beta^0$  behind the phase of the potentiometer current  $OR$ . The measured p.d. across 100 ohms in the resistance  $R$  will be 0.2285 volt, also lagging  $\beta^0$ .

In reducing the capacitance of  $C$  from infinity to zero, the circular locus of potential across  $pp'$  has nearly covered three quarters of its entire circle. It is evident from a consideration of Fig. 3, that if, with the condenser shorted, additional inductance could have been inserted in the circuit, while retaining all other conditions constant, the remainder  $AO$  of the circular locus might also have been traversed.

The use of the new potentiometer thus enables this circular potential and current locus, at telephonic frequency, to be demonstrated observationally, instead of remaining on a purely abstract mathematical basis.

#### SIMPLE $RLC$ CIRCUIT OF SHARPER RESONANCE.

Another example of varying the series capacitance in a simple a.-c. circuit, but at a frequency of 2010~, is given in Fig. 4. Here almost the entire circular locus of potential and current is covered

by the observations, which, shown as round dots, lie close to the circle  $OABD$ , except for an accidental wide unobserved gap between 0.019 and 0.022 microfarad. In this case, the resistance of the circuit was 250 ohms, and this relatively small resistance involves a relatively large change in the vector impedance near resonance, com-

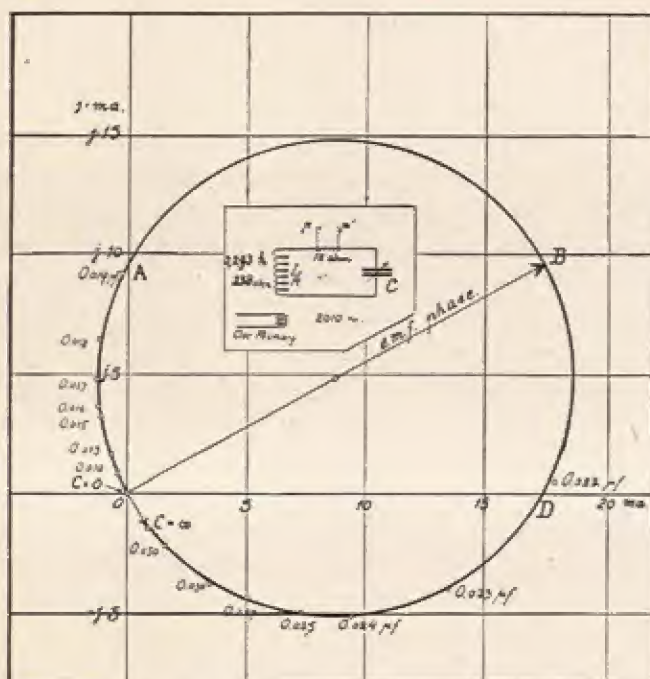


FIG. 4. Current-locus for conditions similar to those of Fig. 2, but applying to a circuit of smaller resistance, and to an impressed frequency of 2010~.

puted at 0.0214 microfarad, with a small change of capacitance. It may be noted that in this case a change of 250 ohms in the condenser reactance changes the vector current, from resonance, through  $45^\circ$  difference of phase, or over a quarter of the circular locus. As the resistance  $R$  in the circuit is reduced, a correspondingly smaller change in reactance, from the resonant point, will produce this  $45^\circ$  change in the vector current. An a.-c. potentiometer can thus serve to measure a small capacitance with precision, by observing



the vector change of current thereby produced in a sharply tuned resonant circuit of low resistance, when the condenser is inserted or removed. Other applications of the same principle will suggest themselves.

#### SIMPLE $RLC$ CIRCUIT WITH VARIATIONS MADE FIRST IN $R$ ALONE, AND THEN IN $C$ ALONE.

An example of a simple  $RLC$  circuit, with successive variations in resistance and capacitance, is presented in Fig. 5. Here the total resistance in the circuit could be given different assigned values between 52 and 802 ohms. The capacitance could also be varied between infinity and 0.20 microfarad. The p.d.'s were measured across taps  $pp'$ , Figs. 2 or 4, and the current strengths determined therefrom. The constant inductance in the circuit was 0.1 henry. The frequency was 1006~ throughout. This produces resonance in the circuit at  $C=0.25$  microfarad.

If we plot the impedance of a  $RLC$  circuit, like that of Fig. 4, at any constant frequency, we obtain an impedance diagram of the type represented in Fig. 6. If we maintain constant resistance in the circuit, such as  $r_4=402$  ohms, and vary only the capacitance, the impedance locus will lie along the straight line  $AB$ . Such a variation of impedance, substituted in equation (6), will, as we have already seen, give rise to a circular current locus, the diameter of the circle coinciding with the vector  $E$  of impressed e.m.f. If, however, we keep the reactance constant, at some value such as  $x_4=j316.2$  ohms, Fig. 6, and vary the resistance, the vector impedance will move over the straight-line locus  $DE$ . This vector impedance, inserted in (6), will also give rise to a circular locus; but the diameter of this circle will be in quadrature with the vector of impressed e.m.f. In the particular case of resonance, where the reactance is kept at zero, and the resistance is varied, the current locus will be a circle of infinite radius; i.e., a straight line, coinciding with the vector of impressed e.m.f. These results are brought out experimentally in Fig. 5. It will be observed that with a capacitance of 0.25 microfarad, the locus coincides with the straight line  $OR$ . The vector impressed e.m.f. was so adjusted, by preliminary tuning of the potentiometer circuit, as to coincide with this line.

All of the circles of constant resistance have their centers on the line  $OR$ , or axis of reals.

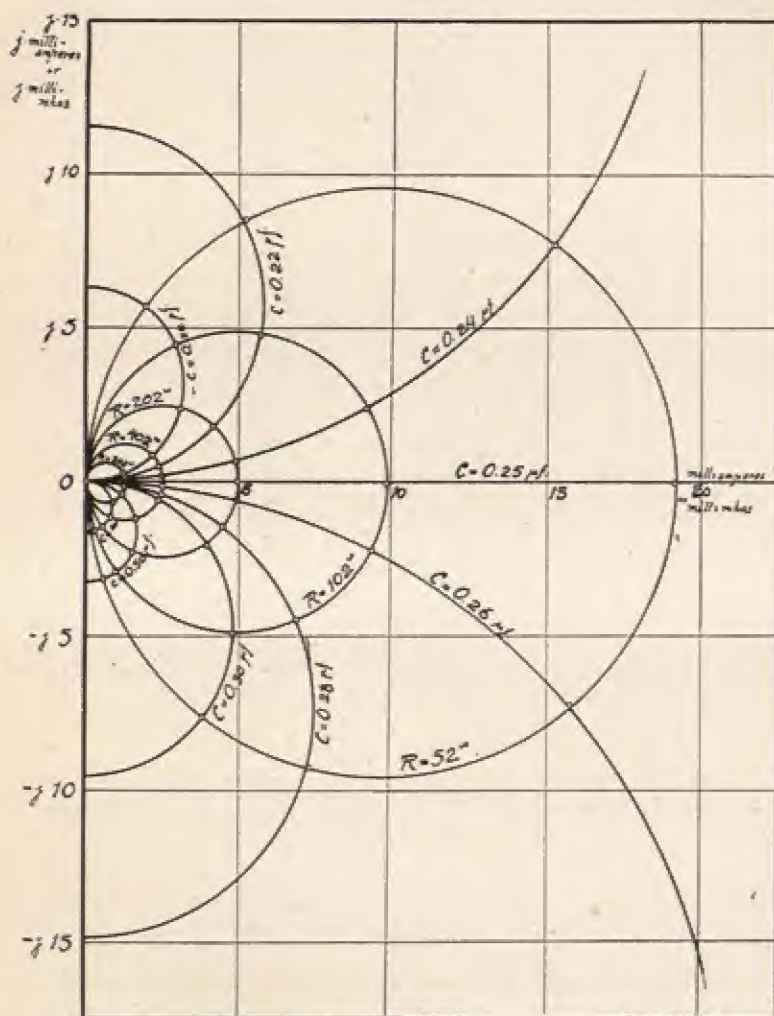


FIG. 5. Graphs of vector current or vector admittance for a  $RLC$  circuit, in which either  $R$  or  $C$  is varied alone.

In Fig. 5, the full lines are the theoretical loci and the small circles the actual potentiometer readings. Fig. 6 is obtained by inver-



sion from Fig. 5, and shows the vector loci of impedance in the circuit, the full lines being computed. The small circles indicate the experimentally deduced results.

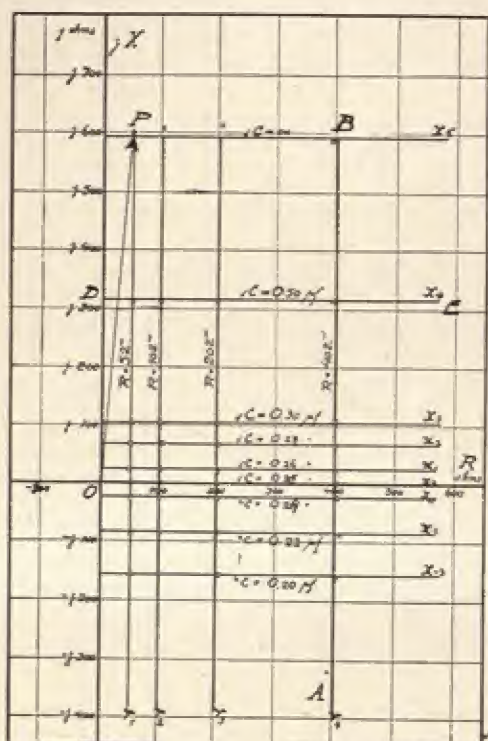


FIG. 6. Graphs of vector impedance for a  $RLC$  circuit, in which either  $R$  or  $C$  is varied alone.

#### DIVIDED CIRCUIT WITH INDUCTANCE AND CAPACITANCE IN PARALLEL.

If we take a simple  $RLC$  circuit, such as that shown in Figs. 2, 4 and 5, and shunt some part of the fixed inductance with an adjustable condenser, we obtain the connection diagram of Fig. 7a, where the inductance coil  $l$ , separate from the oscillator secondary, is shunted by the variable condenser  $c$ . Commencing with  $c=0$ , or the condenser removed, the vector current in the circuit, as deduced from the p.d. across the 10 ohm taps  $pp'$ , was the vector  $Ol=3.6$

$+j13.6 = 14.07 \angle 75^\circ.2$  milliamperes, at 525~, Fig. 7b. As the capacitance in the condenser  $c$ , Fig. 7a, is increased from 0 to infinity, the current locus goes over the circular path  $mlpk$ , Fig. 7b.

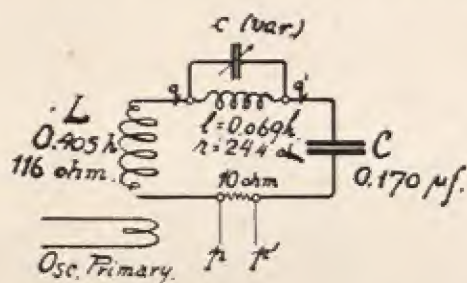


FIG. 7a. Circuit of inductance, resistance, and capacitance, where one part of the inductance is bridged by a variable condenser  $c$ .

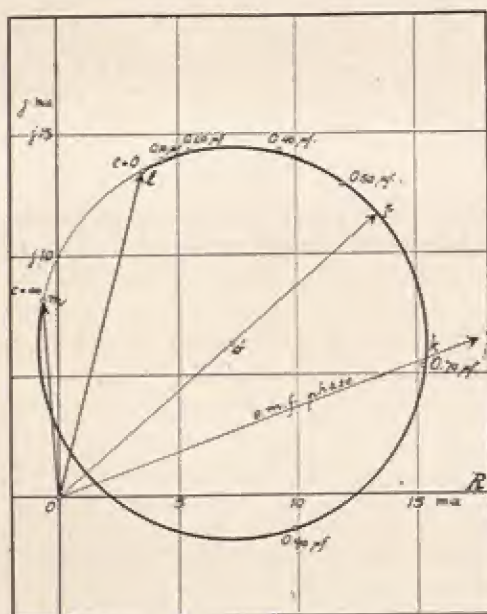


FIG. 7b. Locus for the main current in the circuit of Fig. 7a, the condenser  $c$  being varied from 0 to  $\infty$ , and the impressed e.m.f. being maintained constant, at 525~.

The phase of the e.m.f. induced in the coil  $L$ , Fig. 7a, is represented by the vector  $Ok$ , Fig. 7b.





impedance is  $OM = 464.7 \angle 74^\circ.25$ . At  $c=0$ , the vector impedance is  $OL = 266.2 \angle 55^\circ.6$  ohms. The angle  $mol$  in Fig. 7b is the same ( $19^\circ$ ) as the angle  $MOL$  in Fig. 8. As  $c$  is increased from  $c=0$  to  $c=\infty$ , the vector impedance pursues the wide circle  $LPGM$ .

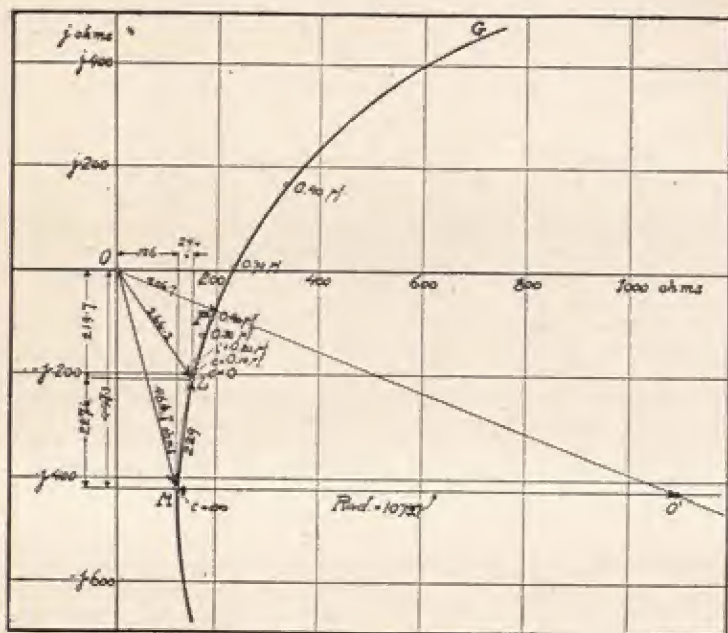


FIG. 8. Locus diagram obtained by inversion from Fig. 7b, and showing the variation of total main-circuit impedance of the main-circuit of Fig. 7a.

The explanations for these interesting circular graphs of Figs. 7b and 8, appear step by step in Fig. 9. Fig. 9a shows the vector admittance of the  $lc$  combination in Fig. 7a, as taken between the points  $qq'$  in the main circuit.  $Ol$ , Fig. 9a, is the fixed admittance of the coil  $l$ , Fig. 7a, at the constant impressed frequency of  $525\sim$ ; namely  $0.4656 - j4.343 = 4.369 \angle 83^\circ.53'$  millimho. The admittance of the condenser  $c$  will be  $jc\omega$ . The vector sum of  $Ol$  and  $jc\omega$  will evidently lie on the straight line  $lm$ , as  $c$  varies from 0 to  $\infty$ . The corresponding impedance of the  $lc$  combination, between points  $qq'$  in the main circuit, Fig. 7a, will be the vector reciprocal of the straight line locus  $lm$ , Fig. 9a, and must therefore be a circle, as has





so that

$$b = \frac{x_1}{|z^2|} = \frac{l\omega}{r^2 + l^2\omega^2} = \frac{1}{l\omega + \frac{r^2}{l\omega}} \quad \text{mhos.} \quad (9)$$

Consequently, at minimum admittance and maximum impedance,

$$c\omega = \frac{1}{l\omega + \frac{r^2}{l\omega}} \quad \text{mhos} \quad (10)$$

or

$$c = \frac{1}{l\omega^2 + \frac{r^2}{l}} \quad \text{farads.} \quad (11)$$

It may be noted that the condition of maximum-impedance in the  $lc$  combination, and which has been defined as "parallel resonance," corresponding to zero total susceptance, differs from the condition of simple series resonance within the  $lc$  circuit, which occurs when the total reactance is zero, or when

$$c\omega = \frac{1}{l\omega} \quad \text{mhos.} \quad (12)$$

This condition is found in the diagram, Fig. 9a, at the total vector admittance  $os$ , when the capacitance in  $c$  is  $1.332 \mu f$ . This occurs when the angle  $sol$ , Fig. 9, is  $90^\circ$ , or when the angle  $uso$  is equal to the angle  $uol$  of the coil's admittance. The angle  $sou$  is  $6^\circ.7'$ , the complement of  $uol$ .

In Fig. 9b, the impedance  $OS$  of the  $lc$  combination is that which is presented at series resonance. It has the value  $2135 \angle 6^\circ.7'$  ohms. The angle  $SOU$  is the same as the angle  $sou$ . At the capacitance  $c = 1.317 \mu f$ , the p.d. at  $qq'$ , on the  $lc$  combination, will be in phase with the main current.

If we increase the impedances of Fig. 9b by the fixed impedance in the remainder of the circuit, Fig. 7a, we obtain the total circuit impedance as shown in Fig. 9c, where  $OM'$  is the vector impedance  $126 - j447.3 = 464.7 \angle 74^\circ.16'$ . If we add to this fixed impedance,  $OM'$ , the vector circle  $LUS$  of Fig. 9b, we obtain the resultant vec-



tor locus  $M'K'H'U'Q'$  of Fig. 9c. As the capacitance in  $c$  varies from 0 to  $\infty$ , the impedance in the main circuit varies from  $OL'$  to  $OM'$ , around the circular arc  $H'Q'$ .

The vector  $OP' = 206.7 \angle 20^\circ.26'.49''$  ohms, is the point of apparent resonance or minimum impedance in the main circuit; *i.e.*, maximum main current, as the result of adjusting condenser  $c$ . It is not a true resonant point, since there is neither cophase, zero resistance, zero susceptance nor equality of undamped frequencies.

The vectors  $OK'$  and  $OH'$  are two cophase vectors, at each of which the current in the main circuit is in phase with the main impressed e.m.f. In general, there will be either two such cophase points, or none. A single cophase point may, however, present itself as an intermediate case. Such cophase points are, in general, not to be classed as resonance points.

The vector points,  $U'$  and  $S'$ , corresponding to  $U$  and  $S$  in Fig. 9b, and also to  $u$  and  $s$  in Fig. 9a, are only of secondary signification in relation to the main-circuit impedance. That is to say, although they correspond to local-circuit resonances in  $lc$ , they do not, in general, represent main circuit resonances.

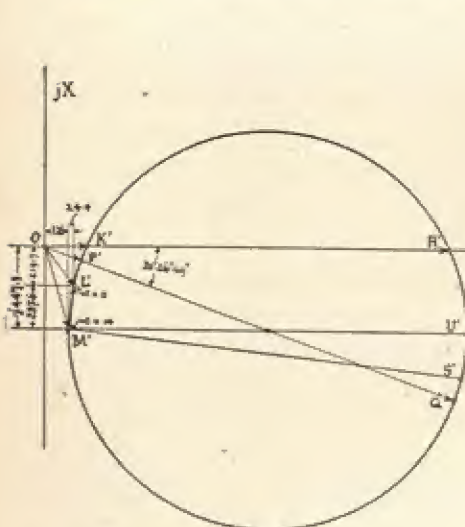


FIG. 9c. Total impedance of circuit including  $l$  and  $c$  in parallel, as obtained from the vector addition of  $OM$  to the locus of Fig. 9b.

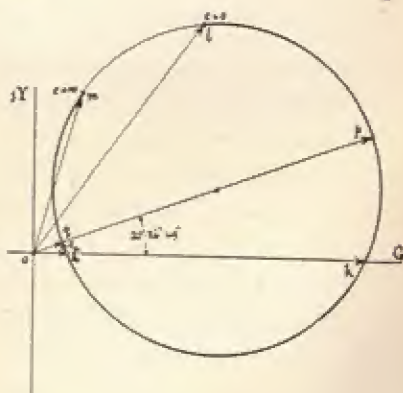


FIG. 9d. Total admittance of circuit as obtained by inversion from Fig. 9c.

Finally, the vector  $OQ'$  represents the maximum impedance of  $2357 \angle 20^\circ.26'.49''$  ohms. It is in cophase with the vector  $OP$  of apparent resonance.

If we invert the impedance graph  $L'P'H'Q'$  with respect to the origin  $O$ , by plotting reciprocals of the corresponding vectors, we obtain the total admittance graph of Fig. 9d. This pursues the circular locus  $lpkhm$ , as  $c$  varies from 0 to  $\infty$ . This may also be regarded as a main current graph to a suitable scale of amperes, with the voltage at reference phase  $OG$ . The vector admittance and current will have a maximum at  $Op$ , the point of apparent resonance, cophase points at  $k$  and  $h$ , minimum at  $q$  and local internal resonances of the  $lc$  loop at  $u$  and  $s$ .

Fig. 7b shows the circular locus observations in the main current corresponding to Fig. 9d; while Fig. 8, deduced from 7b, corresponds to Fig. 9c. It is therefore brought out experimentally, with the new potentiometer, what has perhaps hitherto been known only in abstract theory, that the variation of pure reactance in a branch circuit gives rise to circular-locus current variations in the main circuit.

The experimental case, presented in Fig. 7, corresponds to that of a radio receiving system, in which  $L$  and  $C$  correspond to the antenna path to ground. The loop circuit  $lc$  then corresponds to an oscillation circuit conductively connected with the antenna,  $c$  being tuned to bring about maximum antenna current.

#### COMPOSITION AND RESOLUTION OF VECTOR CIRCULAR LOCI.

The vector loci of current in the fixed inductance  $l$  and the condenser  $c$ , as the latter is adjusted from zero to infinity, are presented in Fig. 7c. These take the form of circles marked respectively  $I_l$  and  $I_c$ . The vector sum,  $I_m$ , or main current in the circuit  $LC$  of Fig. 7a, is reproduced from Fig. 7b to e.m.f. standard phase. It may be noted that in these three circles the maximum or diametral values of current strength occur at different condenser settings.  $I_m$  has its maximum near  $c = 0.5 \mu f.$ ,  $I_l$  near  $0.7 \mu f.$ , and  $I_c$  near  $0.9 \mu f.$

It has already been shown that the circular variation of impedance in the condenser, by reason of its adjustment, gives rise to a



current of circular locus in the main circuit. The p.d. at the terminals  $qq'$  must also have a circular locus, as it consists of the vector difference between the constant impressed e.m.f.  $E$ , and a vector drop of circular locus due to a circular-locus current in the constant impedance of  $L$  and  $C$ . Consequently, the fixed branch  $I$  must receive a current of circular locus. The current in the variable condenser branch must also have a circular locus, as will be seen from the following relations. The main current  $I$  is

$$I = \frac{E}{Z + \frac{1}{g + j\omega c}} \quad \text{amperes } \angle \quad (13)$$

$$= \frac{E(g + j\omega c)}{(1 + Zg) + jZc\omega} \quad \text{amperes } \angle \quad (14)$$

where  $g$  is the fixed admittance of the coil  $l$  or  $1/(r + jl\omega)$  in mhos  $\angle$ , and  $Z$  is the fixed impedance, in ohms  $\angle$ , of the main  $LC$  circuit, outside of the  $lc$  combination.

This main current  $I$  has already been shown to have a circular locus, in reference to Fig. 9, and the conclusion is confirmed algebraically from (14), by Möbius' theorem, as will be further discussed in the appendix.

The branch current in the condenser  $I_c$  is

$$I_c = I \frac{j\omega c}{g + j\omega c} = \frac{Ej\omega c}{(1 + Zg) + jZc\omega} = \frac{E}{Z - j \frac{1 + Zg}{c\omega}} \quad \text{amperes } \angle \quad (15)$$

In its last form, the expression for  $I_c$  indicates the inversion of a straight line, which shows that  $I_c$  has a circular locus, passing through the origin. The branch current in the fixed inductance  $l$  is

$$I_l = I \frac{g}{g + j\omega c} = \frac{Eg}{(1 + Zg) + jZc\omega} \quad \text{amperes } \angle \quad (16)$$

also evidently a circular locus when  $c$  varies.

Consequently, by analysis based on purely electrical relations, the vector circular locus  $I_m$  is resolved into a pair of component vector circular loci  $I_l$  and  $I_c$ , such that at any assigned value of the

capacitance  $c$ , the vector sum of  $I_t$  and  $I_c$ , corresponding thereto, is equal to the value of  $I_m$  then existing. Moreover, the vector sum of  $OO_c$  and  $OO_t$ , which are respectively the vectors from the origin to the centers of the branch current circles, is equal to  $OO_m$ , the vector to the center of the main current circle.

This process of splitting a main current vector circular locus into branch current circular loci can be indefinitely extended, by subdividing the admittance of any one branch into any desired number of equivalent branch admittances. Thus, by following the known electrical rules of splitting admittances, a vector circular locus, followed by the main current, can be resolved into any desired number of component vector circular loci.

Conversely, when a number of branch circuits, forming divisions of a main circuit containing a steady e.m.f., connect a pair of terminals, and one of them has its impedance varied circularly, the currents in all will undergo circular variation in locus. The vector sum of all the currents in the unvaried branches can be obtained by replacing their several fixed admittances by a single joint admittance, and determining, from electrical considerations, the vector circular locus established in this joint admittance by the circular variation of impedance in the outstanding branch.

#### VOLTAGE DISTRIBUTION ALONG A SERIES OF HIGH-RESISTANCE COILS AT 2010~.

A series of high-resistance coils, such as a megohm box, divided into a number of sections, develops an interesting electrical condition, when used with alternating currents, which does not obtrude itself upon the attention of the observer when such resistances are used in continuous-current tests. This condition is a superposed alternating-current distribution in the coils, due to their distributed capacitance and the relatively high a.-c. potentials which are impressed upon their terminals. In the continuous-current case, the capacitances and applied potentials are present, but the charges are fixed, and these do not interfere with the testing current. The a.-c. phenomenon has been noticed and studied, but does not appear to have been presented in the light of potentiometer measurements.



The connections for the test are indicated in Fig. 11. The high-resistance box  $AB$  of 100,000 ohms, is divided into 10 coils of 10,000 ohms each. The end  $B$  is grounded, and also connected to the resistance tap of the potentiometer. The exploring tap, passing

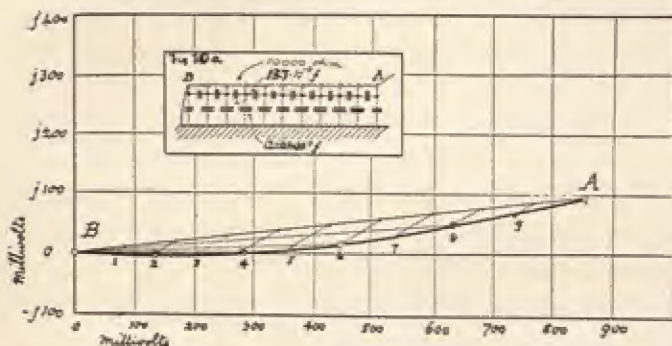


FIG. 10. Vector voltage drop observed along a sectioned high resistance box of 100,000 ohms in 10 coils of 10,000 ohms each, at the frequency of 2,010 cycles per second. Crosses indicate observed, and circles computed values.

through the vibration galvanometer, makes contact in succession with the junctions 1, 2, 3 . . . 10 of the resistance coils, Fig. 11.

The results of an exploration, at 2010~, are presented in Fig. 10. With the potential of the grounded point  $B$  at the origin, the potential at  $A$  was  $855 + j98$  millivolts. If the fall of potential along the coils were regular, the intermediate potentials should have fallen on the straight line  $AB$ , whereas they actually fell upon the curve  $B, 1, 2, 3 \dots A$ . The vector deviations are indicated at each junction, and they affect both size and slope. The reason for this behavior evidently is that, as indicated in Fig. 10a, the resistance box resembles an artificial line, in which the line sections are resistances shunted by condensers; while each section has a condenser leak to ground. The observations indicate that each 10,000-ohm section subtends, at this frequency, an average hyperbolic angle of  $0.13 \angle 15^\circ$ , which would be accounted for by a shunting condenser of 13.7 millimicrofarads per section, and a leak condenser of 0.268 millimicrofarad. The results indicate that the drop of potential in the section nearest to the ground point is very distinctly less than one tenth of the total drop  $BA$ , and that in the sections near  $A$

very distinctly greater. Consequently, when using this subdivided resistance as a volt box, the *B* coils give too small, and the *A* coils too large a result.

It may be observed that it is impossible completely to avoid the introduction of these virtual shunting and leak condensers, in the construction of high-resistance boxes for a.c. tests. If these vir-

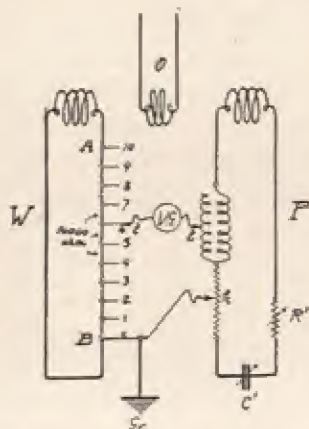


FIG. 11. Exploration, by means of the potentiometer *P*, of the voltage drop along a high-resistance box *AB*, of 100,000 ohms.

tual condensers are dissymmetrical, and vary from coil to coil, it becomes very difficult to make a proper correction for the error due to charging currents. If, however, care is taken to preserve symmetry of structure throughout the resistance box, so that the distributions of virtual capacitance remain uniform from coil to coil, the correction may be readily computed, at any impressed frequency, by hyperbolic functions, according to the well-known theory of artificial lines, from a single set of observations for determining the line constants. A knowledge of the error will thus virtually eliminate the error. Suitably supported and connected metallic ground shields, surrounding each resistance coil, would serve to distribute the leak capacitance uniformly. High-resistance section boxes should, therefore, be designed so as to subtend small hyperbolic angles per section; but whatever the section angle is, it should be regular throughout.





inductance  $L$ , of negligible resistance, was used as a receiving-end load. The received current was measured by observing the p.d. across the last resistance section  $pp'$  of the artificial line.

With the inductance  $L$  reduced to zero, the receiving-end current was observed to be the vector  $OD = 1.03 \times 10^{-3} \angle 37^\circ$  milliampere. The formula for  $I_B$  is

$$I_B = \frac{1.0 \angle 0^\circ}{z_0 \sinh \theta + jL\omega \cosh \theta} \quad \text{amperes } \angle \quad (17)$$

where  $z_0$  is the surge impedance of  $439 \angle 43^\circ.6$  ohms,

$\theta$  is the angle subtended by the line  $2.0 \angle 44^\circ.3$  hyphs  $\angle$ ,

$\omega$  is the impressed angular velocity  $= 2\pi \times 1208 = 7590$  radians/sec.

With  $L=0$ ,  $I_B$  becomes  $1.035 \times 10^{-3} \angle 37^\circ.4$  ampere.

By giving to  $jL\omega$  successively increasing values up to  $j2640$  ohms, the observed received current strength was found to pursue the circular locus  $DPO$ . This circle has its diameter at  $OP$ , when the value of the reactance is 352 ohms. At this condition, the received current strength was a maximum at  $1.4 \times 10^{-3} \angle 80^\circ$  ampere.

The sector of the circle in Fig. 12 between  $O$  and  $D$  might have

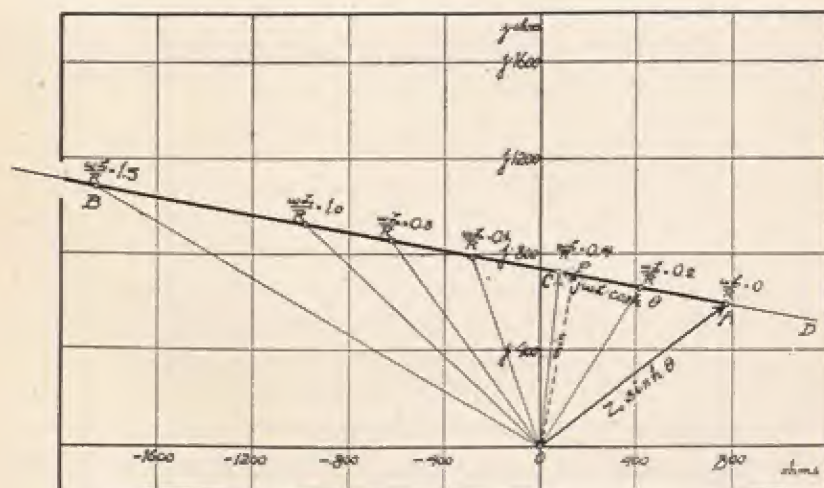


FIG. 13. Rectilinear graph of receiving-end impedance for case presented in Fig. 12, as the load of receiving-end inductance is varied, without changing the resistance from zero value.



been covered, if a condenser had been substituted for the inductance load.

Fig 13 shows why a circular current graph might be expected in this case at the receiving end. The denominator in formula (17) contains the vector sum of a fixed impedance  $z_0 \sinh \theta$  and the variable impedance  $jL\omega \cosh \theta$ . In this term  $\omega$  and  $\cosh \theta$  are constant, so that  $L$  is the only variable. The vector  $OA$ , Fig. 13, represents  $z_0 \sinh \theta$ .  $AC$  is the vector  $jL\omega \cosh \theta$ , for  $L$  corresponding to  $L\omega/R = 0.4$ . The vector sum  $z_0 \sinh \theta + jL\omega \cosh \theta$  is then  $OC$ . To successive values of  $L$ , from  $L = 0$  to  $L = 0.175$  henry, correspond successive distances from  $A$ , along the straight line  $AB$ . The vector locus of the sum appearing in the denominator of (17), is therefore a straight line. The reciprocal of this vector sum must consequently follow a circular locus, and corresponds to the circular locus of Fig. 12.  $OP$  is the perpendicular from the origin to the line  $AB$ . The point  $P$  thus marks a minimum receiving-end impedance, and a maximum received current. This corresponds to a certain type of resonance.

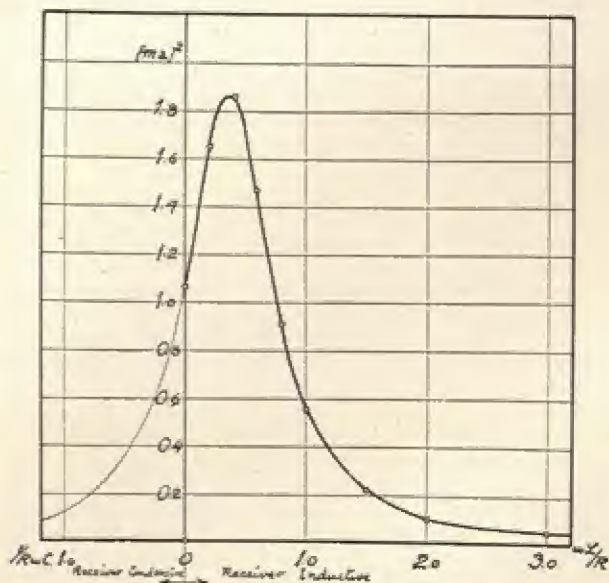


FIG. 14. Resonance curve of received current strength squared against the ratio of receiving end reactance to total resistance.

If we plot the square of the received current strength of Fig. 12, as scalar ordinates, to  $L\omega/R$  as abscissas, we obtain the resonance curve of Fig. 14. It follows from the linear relations of  $L\omega/R$  along the straight line  $AB$ , in Fig. 13, that the ordinates of the resonance curve in Fig. 14 will lie symmetrically at equally spaced abscissas on each side of the maximum. If a condenser had been used as a receiving-end load beyond the point  $L=0$ , the part of the resonance curve, Fig. 14, on the left-hand of the origin, might have been covered.

#### PREVALENCE OF CIRCULAR VECTOR LOCI.

It may be noted that in the cases of Figs. 2, 4, 5, 7, 9 and 12, circular graphs of vector potential loci have presented themselves, and many measurements in the laboratory, at constant frequency, lead to such circular graphs.

If we consider any fixed network of conductors, we may assume that all joints are electrically good, all leaks are steady, and all iron cores removed from the inductances; or, in other words, assume that each and all of the elements of the network obey Ohm's law.

Let us select arbitrarily any pair of terminals  $AB$  in the network, at which a constant simple alternating e.m.f. is applied, in the steady state, at a fixed frequency, and also select any other pair of terminals  $CD$  in the network, at which the effects of the applied e.m.f. are to be looked for. It will be shown, in the Appendix, that if we introduce, between  $C$  and  $D$ , an impedance which varies along a circular locus in the impedance plane, a straight line variation being included as a particular case, then both the current and voltage will be caused to vary along a circular locus at  $CD$ . Moreover, the current and sending-end impedance at the terminals  $AB$  will be caused to vary along a circular locus. Again, if a circularly varied impedance is inserted between the impressed e.m.f. and the  $AB$  terminals, the voltage and current at those terminals will be caused to vary circularly, and also the voltage and current at  $CD$ . A further development of this remarkable phenomenon will be found in the Appendix. It means that a conducting network has a wonderful propensity for reproducing impressed circular variations. A network of  $n$  elements, in one of which a circular variation of impe-



dance or admittance is impressed, will give rise to  $n-1$  new circular variations of current; *i.e.*, one in each of the other elements, assuming all impressed e.m.f.'s simultaneously acting on the system remain constant. The circular variations in terminal *p.d.*'s throughout the system will be of the order  $n^2$ , neglecting intermediate potentials between terminals.

## APPENDIX.

### CIRCULAR VARIATION IN NETWORKS OF CONDUCTORS.

It is proposed to establish the following main proposition:

In any network of conductors, all the elements of which obey generalized Ohm's law, subjected in the steady state to any frequency of constant e.m.f. (including zero frequency as the limiting continuous-current case), circular variation of the impedance of any element will produce a corresponding circular variation in the current in every element of the network. Moreover, the *p.d.* between any two points of the network will be caused to vary circularly. The sending-end impedance or admittance between any two points on the network will be likewise caused to vary circularly. By "circular variation" is meant variation over a planevector circular locus, including the straight-line locus as a limiting case.

The prevalence of circular loci in relation to alternating-current circuits has been recognized in the literature of the subject,<sup>5</sup> which contains various scattered theorems bearing upon special cases. A few of these theorems may advantageously be collated here in presenting the demonstration of the main proposition.

It was shown by Clerk Maxwell<sup>6</sup> that if, in any continuous-current network, two terminals, say *A* and *B*, are selected as sending-end terminals, and two other terminals, say *C* and *D*, are selected as receiving-end terminals, a current *I* applied to the network at *AB* would produce the same *p.d.*, at *CD*, as would be produced at *AB*, if the same current *I* were applied at *CD*. This theorem may be

<sup>5</sup> Bibliography, 5, 6, 7, 7a, 10.

<sup>6</sup> Bibliography, 3; also 4, 8.

given an interesting interpretation in terms of the equivalent  $T$  of the network, with regard to terminals  $AB, CD$ . By generalization from several well-known examples of equivalent  $T$ -s, LaCour<sup>7</sup> demonstrated that any a.-c. or d.-c. network can be replaced by a certain equivalent  $T$ , in general dissymmetrical, so that this  $T$ , insofar as regards conditions at  $A, B, C, D$  will be the exact equivalent of the actual network.

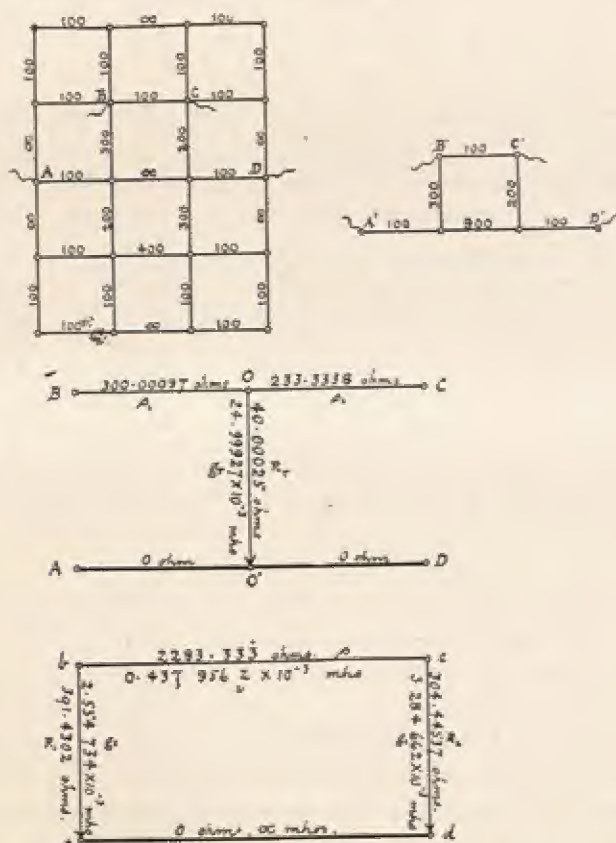


FIG. 15. Continuous-current network with its equivalent  $T$  and  $\Pi$ .

As a simple example, we may consider the continuous-current plane network of Fig. 15. The resistances of the various elements in ohms are marked thereon. Some of them are made infinite, in

<sup>7</sup> Bibliography, 7 and 70.



order to simplify the computation. With respect to the pairs of terminals  $AB$  and  $CD$ , this network reduces to the  $A'B'C'D'$  connection of six elements. By any of the known processes, this may be reduced to the equivalent  $T$  of Fig. 15*b*, in which the staff resistance is 40.00025 ohms. It is evident that 1 ampere applied to this  $T$  at the  $AB$  terminals, will produce 40.00025 volts at  $CD$ , and that reciprocally 1 ampere applied to this  $T$  at the  $CD$  terminals will also produce 40.00025 volts at  $BA$ . The "mutual impedance"<sup>8</sup> of the network between the pairs of terminals  $BA$  and  $CD$  is thus 40.00025 ohms.

Maxwell also showed<sup>9</sup> that if continuous e.m.f. were applied at  $AB$ , and a current thereby produced through the terminals  $CD$  when short-circuited, the same e.m.f. applied at  $CD$  would produce the same current through the terminals  $AB$  short-circuited. A similar theorem had been enunciated already by Kirchhoff.<sup>10</sup>

This proposition may, in a similar way, be given an interpretation in terms of the equivalent  $\Pi$  of the network. In Fig. 15*c*,  $bca d$  is the equivalent  $\Pi$  with respect to the terminals  $AB$ ,  $CD$ . It is evident that an e.m.f. of 1 volt applied at  $ba$  would produce a current of 0.4379562 milliamperes at  $cd$ , and that reciprocally, 1 volt at  $cd$  would produce the same current at  $ab$  shorted. In other words, the mutual admittance of the network with respect to the two selected pairs of terminals is the architrave admittance of the equivalent  $\Pi$ . Moreover, the equivalent  $\Pi$  of mutual admittance is the conjugate system of the equivalent  $T$  of "mutual impedance," and may be directly computed therefrom. Consequently, if the "mutual impedance"  $T$  of a network, with respect to two pairs of terminals, has been ascertained, the mutual admittance  $\Pi$  of the same network and terminals can be deduced by  $\Pi$ - $T$  substitution and without further experimental investigation.<sup>11</sup>

In Fig. 16, a relatively simple alternating-current plane network example is worked out. The impedance of each element of the nine-element network is marked thereon. The selected terminals are  $AB$  and  $CD$ . The equivalent  $T$  is shown in Fig. 16*b*, and the

<sup>8</sup> Bibliography 12.

<sup>9</sup> Bibliography 3, 4, 8.

<sup>10</sup> Bibliography 1, p. 32.

<sup>11</sup> Bibliography 6a.

equivalent  $\Pi$  in Fig. 16c. The "mutual impedance" of the network for these pairs of terminals is  $10.48605 \angle 95^\circ.00'.47''$  ohms, and the mutual admittance  $0.936265 \times 10^{-3} \angle 34^\circ.59'.31''$  mho.

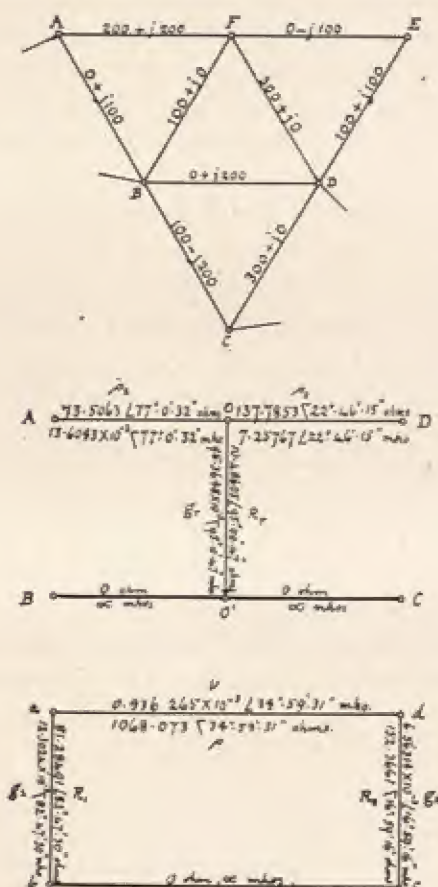


FIG. 16. Alternating-current network with its equivalent  $T$  and  $\Pi$ .

In any actual network, it is theoretically easy to determine the elements of the equivalent  $T$  experimentally. It suffices to measure  $E_{CD}$  and  $I_{AB}$  in order to determine  $R_T$ . A measurement of the sending-end impedances at each pair of terminals in turn, will then serve to evaluate  $r_1$  and  $r_2$ . Similar treatment applies to the experimental determination of the  $\Pi$ , if this is preferred.



In the equivalent  $T$ 's of Figs. 15 and 16, all of the series impedance appears in the upper arms, and none in the lower arms. All of the impedance might, however, be transferred to the lower arms, without altering the equivalence of the circuit. Moreover, any desired share of impedance might be transferred from the upper to the lower arms, according to the rules of  $T$  and  $I$  equivalent circuits.<sup>12</sup> Similarly, the architrave impedance of the  $\Pi$ 's of Figs. 15 and 16 may be either wholly or partly transferred to the lower line.

In any dissymmetrical  $T$  and its conjugate  $\Pi$ , we have the relation

$$\frac{\rho_1}{\rho_2} = \frac{R_1}{R_2} = \frac{g_2}{g_1} \quad \text{numeric } \angle \quad (18)$$

In the case of Fig. 15, this ratio is 1.2857. In the case of Fig. 16, it is  $0.53348 \angle 99^\circ 46'.47''$ . This also means that in any a.-c. case, the difference in the slopes of  $\rho_1$  and  $\rho_2$  will be the same as the difference in the slopes of  $R_1$  and  $R_2$ , or

$$\bar{\rho}_1 - \bar{\rho}_2 = \bar{R}_1 - \bar{R}_2 = \bar{g}_2 - \bar{g}_1 \quad \text{degrees} \quad (19)$$

this difference being  $99^\circ 46'.47''$ .

Again in any dissymmetrical  $T$  and its conjugate or equivalent  $\Pi$ , the geometrical mean of the two  $T$ -arm impedances, times the architrave admittance equals the geometric mean of the two  $\Pi$ -leak admittance times the  $T$ -staff impedance, or

$$\nu \sqrt{\rho_1 \rho_2} = R_r \sqrt{g_1 \cdot g_2} \quad \text{numeric } \angle \quad (20)$$

In the case of Fig. 15, this product is 0.11587. In that of Fig. 16, it is  $0.094224 \angle 62^\circ 6'.40''$ . From this relation it also follows that

$$\bar{R}_r + \bar{g}_1 = \bar{r} + \bar{\rho}_2 \quad \text{degrees} \quad (21)$$

In the case of Fig. 16, this quantity is  $12^\circ 13'.16''$ .

Returning now to the main proposition, if an alternating-current network is connected, at the receiving-end terminals  $DC$ , to a circularly varied impedance load, the impedance of the circuit  $ODCO'$ ,

<sup>12</sup> Bibliography 11 and 11a.

Fig. 16*b* will also have circular variation, and the admittance of this branch, including this load, must also vary circularly by the geometry of inversion.<sup>13</sup> If, then, we add the constant admittance of the staff leak  $g_T$ , Fig. 16*b*, it follows that the total admittance on the right-hand side of  $OO'$  will have circular variation, under circular variation of the load at  $BC$ . Taking the reciprocal of this circular admittance, the impedance of the system on the right-hand side of  $OO'$  will also have circular variation. Adding to this the constant impedance  $AO$ , the total sending-end impedance at terminals  $AB$  must have circular variation, as likewise the sending-end admittance.

Consequently, a circular variation of load at  $DC$  must produce a circular variation of current at  $AB$  under constant impressed e.m.f., or a circular variation of voltage at  $AB$  under constant impressed current.

Again, referring to Fig. 16*c*, if the constant e.m.f. impressed at  $ab$  is  $E$ , and an admittance load  $y$ , which varies circularly, is applied at terminals  $dc$ , then the admittance at  $ab$ , excluding the constant leak  $ab$  is the circularly varying admittance:

$$Y = \frac{1}{\rho + \frac{1}{g_2 + y}} \quad \text{mhos } \angle \quad (22)$$

Hence the entering current in the architrave  $ad$  will be

$$I = EY = \frac{E(g_2 + y)}{1 + \rho(g_2 + y)} \quad \text{amperes } \angle \quad (23)$$

Of this current, the fraction  $y/(g_2 + y)$  will pass through the load and the current  $i$  in this load will therefore be

$$i = \frac{E \cdot y}{1 + \rho(g_2 + y)} \quad \text{amperes } \angle \quad (24)$$

The ratio  $E/i$  is the receiving-end impedance of the loaded system and is

$$Z = \rho + \frac{1 + \rho g_2}{y} \quad \text{ohms } \angle \quad (25)$$

<sup>13</sup> Bibliography 2.



In this expression, if  $y$  varies circularly, so does its reciprocal, and therefore so does  $Z$ . Consequently, if the sending-end impressed voltage is held constant, and  $y$  is varied circularly, the current delivered to the load at the receiving-end will undergo a circular variation. From similar considerations, it may be seen that if the sending-end impressed current is held constant, the voltage at receiving terminals will also undergo circular variation, when  $y$  is varied circularly.

We have hitherto considered the effect of a circularly varied load at the receiving terminals  $CD$ , in producing circular variations of impedance, voltage, and current, both at those terminals and at the sending terminals  $AB$ . We may now consider, in like manner, the effect of circularly varied impedance, voltage and current at the sending end.

Referring to Fig. 16*b*, let the receiving terminals  $DC$  be connected through a fixed impedance load  $\sigma$  ohms  $\angle$ , such that

$$\rho_2 + \sigma = z_2 = \frac{1}{y_2} \quad \text{ohms } \angle.$$

Then the total admittance at  $O$  will be  $g_r + y_2$  mhos  $\angle$ . The total impedance at the terminals  $AB$  is then  $\rho_1 + [1/(g_r + y_2)]$  ohms  $\angle$ . Let an e.m.f. of fixed frequency and constant vector value  $E$  be applied at the terminals  $AB$ , through an impedance  $z_1$  ohms  $\angle$ , which impedance is varied circularly. Then the total impedance  $Z_A$  of the circuit at the sending-end is

$$Z_A = z_1 + \rho_1 + \frac{1}{g_r + y_2} \quad \text{ohms } \angle \quad (26)$$

Since  $z_1$  is supposed to be the only variable, the circular variation of  $z_1$  causes circular variation in  $Z_A$ ; so that the current entering the network at  $AB$  is circularly varied under constant e.m.f.  $E$ ; or, if the entering current should be maintained constant, the impressed voltage  $E$  must be varied circularly to correspond.

The entering current at  $AB$  being

$$I_A = \frac{E}{Z_A} = \frac{E(g_r + y_2)}{(z_1 + \rho_1)(g_r + y_2) + 1} \quad \text{amperes } \angle \quad (27)$$

The current  $I_c$  passing through the constant load  $\sigma$  at  $CD$  is

$$I_c = I_A \cdot \frac{y_2}{y_2 + g_r} = \frac{E \cdot y_2}{(z_1 + \rho_2)(g_r + y_2) + 1} \quad \text{amperes } \angle \quad (28)$$

The denominator in this expression is a vector which undergoes circular variation, when  $z_1$  is varied circularly, and since  $E y_2$  is constant,  $I_c$  must also vary circularly. This means that the receiving-end impedance of the network at  $CD$ , with respect to constant e.m.f. at  $AB$ , undergoes circular variation as  $z_1$  is varied circularly.

If constant current and not constant e.m.f. is impressed at  $AB$ , through a circularly varied impedance  $z_1$ , a similar expression for receiving-end current and voltage at  $CD$  is obtained.

Finally, if with  $z_1$  and  $\sigma$  constant, the impressed e.m.f. and current are varied circularly at  $AB$ , it is manifest that the p.d. and the current in each and every element of the network, including the load at  $CD$ , will be varied circularly and in the same simple proportion. In this case, the circular variations reproduced are all of the same type throughout the network, whereas in the preceding cases discussed, the circular variations produced are, in general, different in the different elements.

We have hitherto considered only the pairs of terminals  $AB$  and  $CD$ . Since, however, these are chosen arbitrarily in the network, the above propositions must apply between any pairs of terminals; so that if the impedance load at any pair of receiving terminals is varied circularly, the impedance of the system, including the load, will be caused to vary circularly at any other pair of terminals. Moreover, if either the current or the voltage impressed at any pair of terminals is varied circularly, the potential and current at any other pair of terminals will be caused to vary circularly. The case of constancy, or zero variation, must be included as belonging to a circular locus of zero radius. Zero variations will occur if the terminals  $AB$  are "conjugate" to the terminals  $CD$ .<sup>14</sup>

Finally, the current in any element of the network must vary circularly when a constant e.m.f. is impressed at any pair of terminals and any other element has its admittance, or impedance, circularly varied. This is seen from an examination of Kirchhoff's or

<sup>14</sup> Bibliography 1 and 3.



Maxwell's demonstration,<sup>15</sup> when the reasoning is extended to complex quantities. It may be seen that in the symbols here employed,

$$i_{rs} = E_{pq} \cdot \frac{A + By}{C + Dy} \quad \text{amperes } \angle \quad (29)$$

where  $i_{rs}$  is the current in the element  $rs$ , when the e.m.f.  $E_{pq}$  is inserted in the element  $pq$ , and  $y$  is the admittance of any third element  $uv$ , which is subject to circular variation; while  $A$ ,  $B$ ,  $C$ , and  $D$  are system constants, independent of  $y$ . It is well known, from the theory of functions of a complex variable, that the linear transformation represented by (29) gives rise to a circular locus, if  $y$  varies along a circle.

It may be noted that by reason of the known principle of vector superposition of currents in a network, the multiplication of circular loci extends to cases where a plurality of e.m.f.'s coexist. The proposition may also be extended to include mutual inductances. Strictly speaking, iron-cored inductances are excluded, however, owing to the imperfect application of Ohm's law to them, under varying permeability and magnetic skin effect.

If the impressed alternating e.m.f. or e.m.f.'s are impure, so that harmonics are present, any rectilinear variation in the impedance or admittance of any element in the network will also be rectilinear for any harmonic frequency, and so will give rise to circular variations in the harmonic voltages and currents throughout the network as well as in the fundamental. In other words, the multiplication of circular variations in a network, due to rectilinear variation in the impedance or admittance of one element, applies not only to the fundamental frequency, but also to any superposed frequencies.

#### SUMMARY.

1. Experimental results obtained with a new type of a.-c. potentiometer are discussed.
2. The circular graphs of current and admittance are analyzed, for the case of a simple  $RLC$  circuit, at the successive constant frequencies of 500, 1,000 and 2,010 cycles per second, when either  $R$  or  $C$  is varied alone.

<sup>15</sup> Bibliography 1, p. 25 and 3, Vol. 1, Section 282a.

3. The circular graphs of current, admittance, voltage and impedance are analyzed for the case of a divided circuit, operated at constant e.m.f. and frequency. The problem of composition and resolution of component and main circular graphs is discussed in the light of the experimental results.

4. The distribution of potential over a sectional high-resistance box is explored, at an impressed frequency of 2,010 cycles per second.

5. The circular graph of receiving-end current is given for the case of an artificial telephone cable operated at constant voltage, and at the frequency of 1,208 cycles per second, when the receiver has variable purely reactive impedance.

6. Certain general propositions are offered concerning the development of vector circular loci in the voltage, current, impedance and admittance of an alternating current network in any steady state. These propositions are shown to be connected with the equivalent  $T$  or  $\Pi$  of the network, with respect to any two pairs of selected terminals.

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## SOME SCIENTIFIC ASPECTS OF THE METEOROLOGICAL WORK OF THE UNITED STATES ARMY.

By ROBERT A. MILLIKAN, PH.D., SC.D.

(Read April 26, 1919.)

There is no more interesting illustration of the application of new scientific methods to warfare than is furnished by the developments in meteorology during the great war. Prior to 1914 a meteorological section was not considered a necessary part of the military service. No corrections had ever been made by the artillery of any army for any save surface winds. Firing by the map was almost unknown. No Sound-ranging Service, no Air Service and no Anti-aircraft artillery had ever existed to demand aërological data.

At the time of the signing of the armistice on the western front the Air Service and all the artillery were being furnished every two hours with the temperature, density, wind-speed and direction, taken at the surface and at various altitudes, from 100 to 500 meters apart, up to 5,000 meters. Further, tables were prepared from which each battery could obtain the correction suited to its trajectory for the so-called ballistic wind. This is, the average wind for the trajectory, weighted for the density of the air at the elevations traversed. Even machine guns when used for barrage work made use of these ballistic-wind tables.

In addition, daily forecasts were furnished to the armies in accordance with the following outline:

- A. Character of weather for each arm of the service.
- B. Winds: Surface at 2,000 m., at 5,000 m.
- C. Cloudiness including fog and haze.
- D. Height of cloud.
- E. Visibility.
- F. Rain and snow.
- G. Temperature.



H. Warning of weather conditions favorable for use of gas by enemy.

K. Probable accuracy or odds in favor of forecast.

Most of the aërological data was obtained from theodolite observations on pilot balloons. The extent to which our knowledge of the upper air has been, and is being, extended by this pilot balloon work may be seen from the fact that before the war there existed but one station in the United States where pilot balloon explorations were regularly carried on. Within a year of the inception of the meteorological service in the United States Army, thirty-seven complete stations for the obtaining of both surface and upper air data in aid of aviation and the artillery had been established in the United States and equipped with special aircraft theodolites and pilot balloons, neither of which had ever been produced before in this country. Further, twenty such stations had been established by our forces abroad. For the manning of this service, about five hundred specially selected men had been trained in this country, and three hundred and fourteen of them sent abroad, while about two hundred were held for work in the United States.

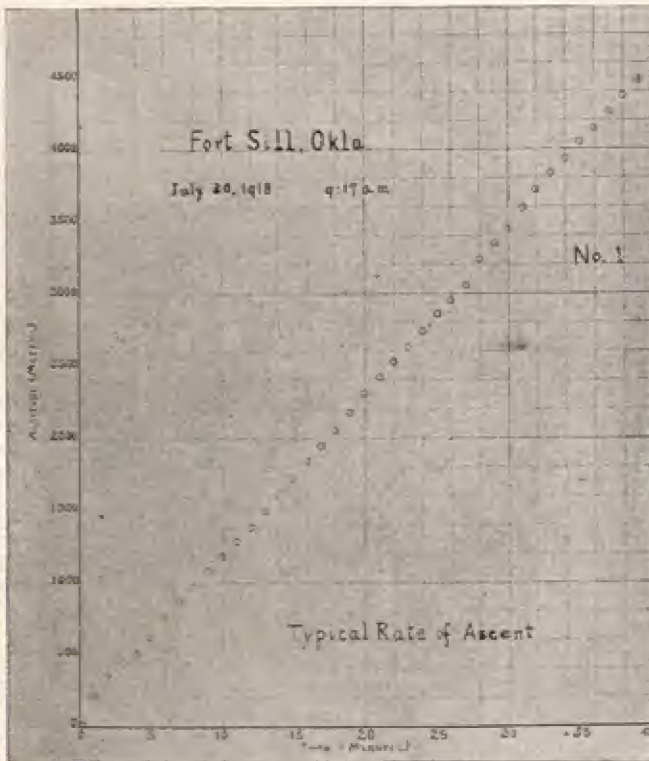
The scientific interest in this service centers about four distinct problems:

1. The extension of our knowledge of the law of motion of pilot balloons.
2. The procurement of data and the development of methods for the preparation of artillery range tables.
3. The development of long range propaganda balloons.
4. The charting of the upper air in the United States and overseas in aid of aviation.

1. *The Extension of Our Knowledge of the Law of Motion of Pilot Balloons.*—Prior to the development of the meteorological service of the army there had been made in the United States perhaps one hundred pilot balloon flights in which the balloons had been followed by the two-theodolite method—the only method which permits of real accuracy—and in several European countries there had been a somewhat greater number, but the data was incomplete and fragmentary.

Within the past year approximately five thousand such observa-

tions have been taken by the meteorological service of the Signal Corps. From these observations the altitude of the balloon is determined with great accuracy by triangulation, the base line being usually a mile or more in length. The balloon is kept in sight up to distances as great as sixty miles, and up to heights as great as 32,000



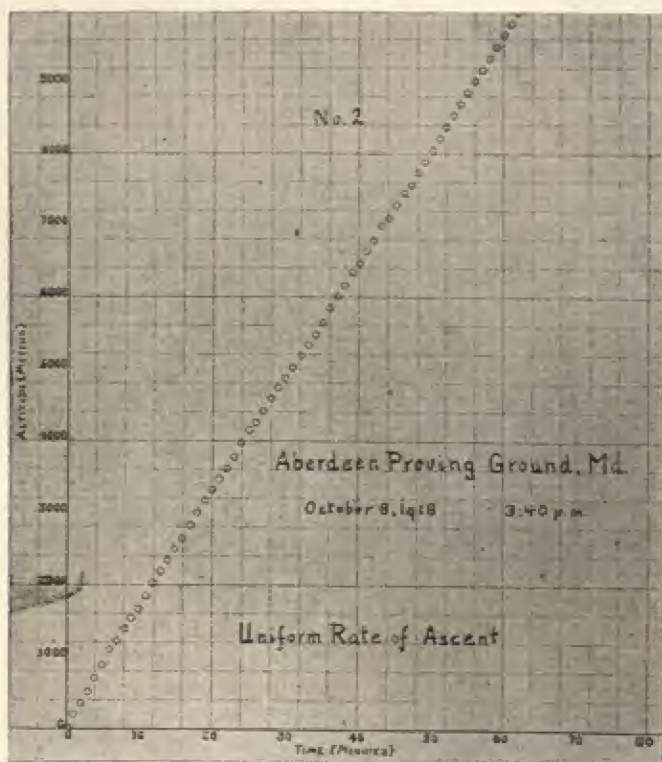
Uniform rate of ascent of pilot balloon up to 4,500 meters.

meters, or approximately twenty miles. For the practical uses of the artillery and the air service, observations need not be carried higher than 10,000 meters (six miles), which is the extreme height to which airplanes have thus far ascended, or to which projectiles usually go.

In view of the number of variables which enter into the rate of ascent of pilot balloons, such as the changing density and the chang-



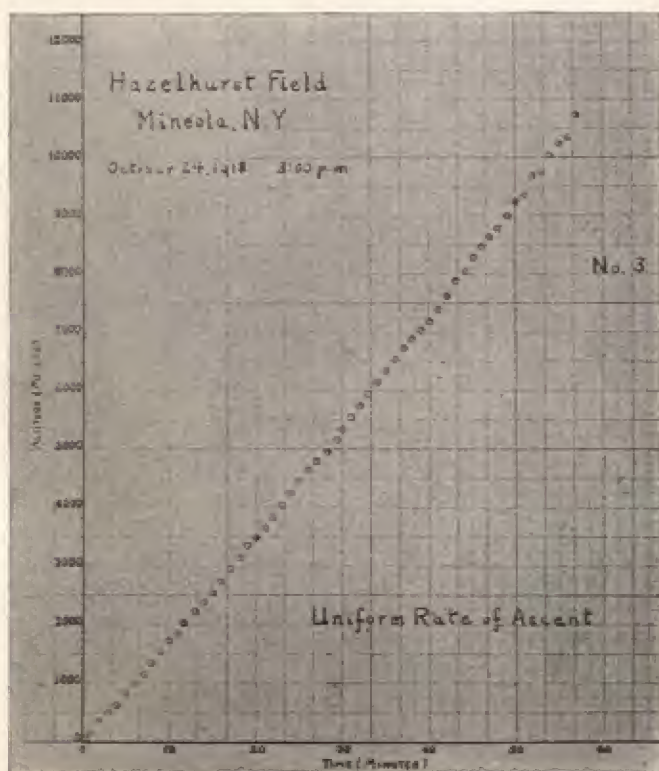
ing temperature of the surrounding air, the changing size of the balloon and consequent changing tension of the rubber envelope, the changing temperature of its interior because of the absorption of the sun's rays, the diffusion of hydrogen through its walls, etc., it is one of the most striking facts to be found anywhere in the annals



Uniform rate of ascent of pilot balloon up to 10,000 meters.

of empirical science that these balloons rise to great heights without deviating appreciably from the simplest possible law of ascent, namely, that of constant speed. Graphs Nos. 1, 2, 3, 4 and 5 show beautiful examples of this constancy. Graph No. 6 shows a kink at about 5,500 meters, which is presumably due to a descending current struck at that altitude. Graph No. 7 shows a balloon followed to a height of 20,000 meters where it apparently developed a

leak and failed to ascend further. Graph No. 8 shows the fluctuations which are often found at low altitudes, these fluctuations being undoubtedly due to ascending and descending currents.

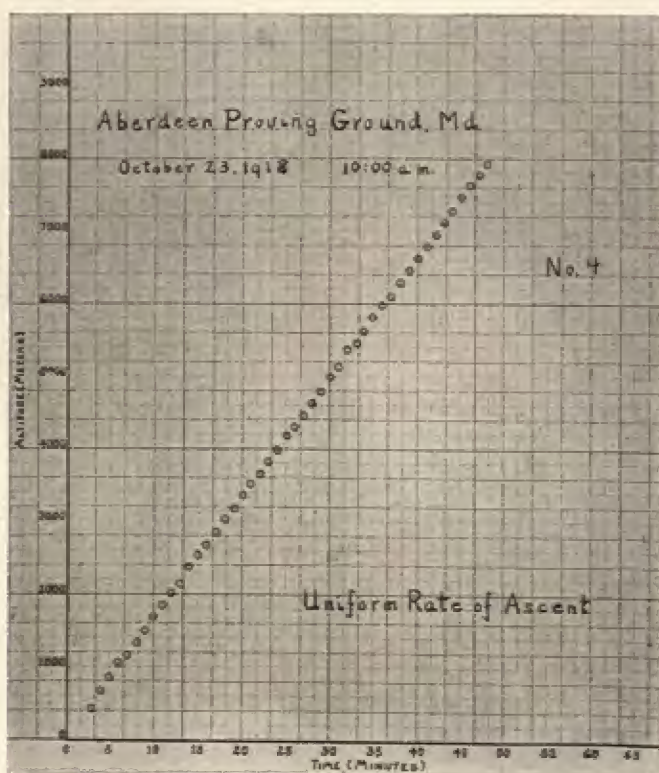


Uniform rate of ascent of pilot balloon up to 11,000 meters.

The extreme constancy in the rate of ascent, shown in a great majority of flights, although surprising enough, is not as inexplicable as it at first appears, for since the pressure within the balloon due to the tension of the rubber itself is only from five to eight centimeters of water, and since this pressure is at sea level less than 1 per cent. of the pressure of the atmosphere, it will be seen that the balloon will expand practically freely, that is, as though the walls did not constrain it at all, up to heights of say 10,000 meters where



the pressure is about a third of an atmosphere. This means that the ascensional force must be entirely independent of temperature and pressure.<sup>1</sup> For the speeds with which these balloons ascend, namely, about three meters a second, the resistance to motion must be directly proportional to the density of the air and experiment

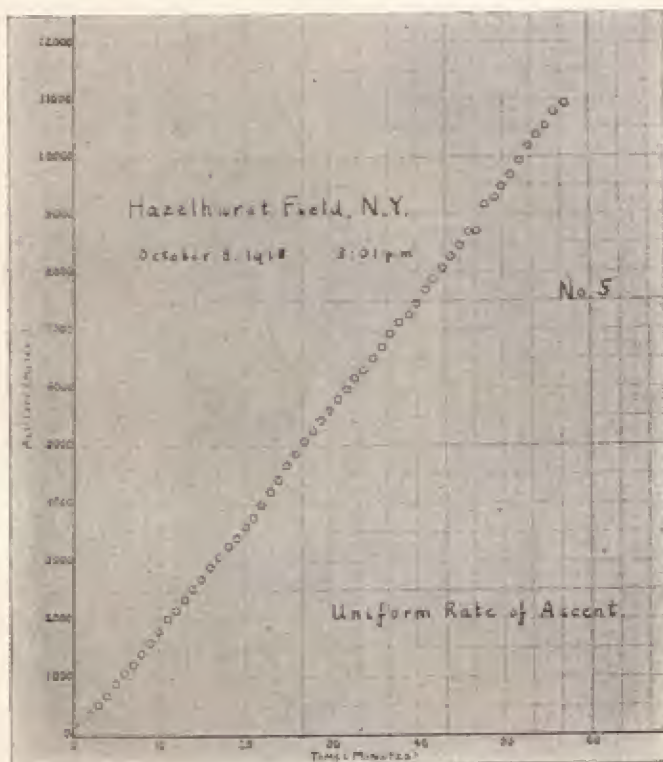


Uniform rate of ascent of pilot balloon up to 8,000 meters.

shows it to be nearly proportional to the cross section of the balloon, that is, to the square of the radius. This makes the resistance vary

<sup>1</sup> For if  $f_1, d_1, v_1, p_1, t_1$  represent ascensional force, density, volume, pressure and temperature at the surface of the earth, and  $f_2, d_2, v_2, p_2, t_2$  the corresponding quantities at any given elevation, then since  $d_2/d_1 = v_1/v_2 = p_1/t_1/p_2/t_2$  (1) and  $f_1/f_2 = v_1 d_1/v_2 d_2$  (2) there results from a combination of 1 and 2,  $f_1/f_2 = v_1 d_1/v_2 d_2 = p_1 t_1/p_2 t_2 \times p_1 t_2/p_2 t_1 = 1$ .

as the cube root of the density,<sup>2</sup> which means that at a height of 6,000 meters, where the density is about one half, the resistance is .83, of what it would be at the surface. If, as is approximately true for these speeds, the resistance varies as the square of the velocity,



Uniform rate of ascent of pilot balloon up to 11,000 meters.

or the velocity as the square root of the resistance, this would mean that the velocity should vary as the sixth root of the density. In

<sup>2</sup> For if  $R_1$  is the resistance at the earth's surface and  $R_2$  that at any given altitude,

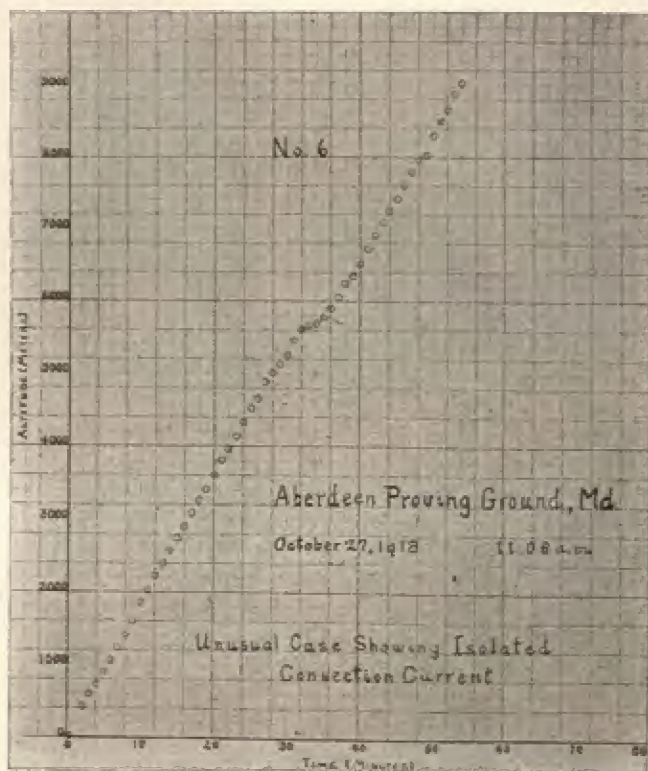
$$\frac{R_1}{R_2} = \frac{V_1^3 d_1}{V_2^3 d_2}$$

which is seen from (1) to equal

$$\left(\frac{d_1}{d_2}\right)^{\frac{1}{3}}.$$



other words, since the sixth root of 2 is 1.13, at a height of 6,000 meters, the velocity should be about 13 per cent. greater than at the surface. Such an increase in velocity would be very easily observable in the experimental data. The fact that it is not found there

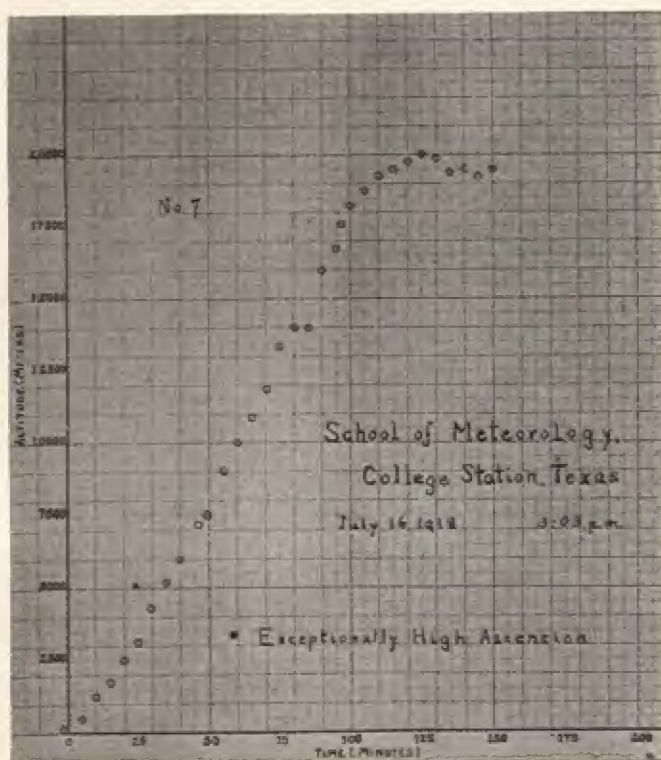


Pilot balloon ascent showing isolated convection current.

is due to the wholly fortuitous circumstance that the slow diffusion of hydrogen through the walls, as observation by Blair and Sherry has shown, is just sufficient, with the balloons here used, to retard the ascensional rate enough to make it quite exactly constant.

This makes it possible, provided one could always duplicate the size and weight of his balloon, to obtain a very exact determination of wind velocity and direction by a one-theodolite method, the height being always known from the time and the known rate of ascent.

When, however, the weight and inflation of the balloons are varied, as they must be in practice, since the balloons vary in weight from twenty to thirty-five grams, and since it is convenient also to vary the filling according as low altitude or high altitude wind-data

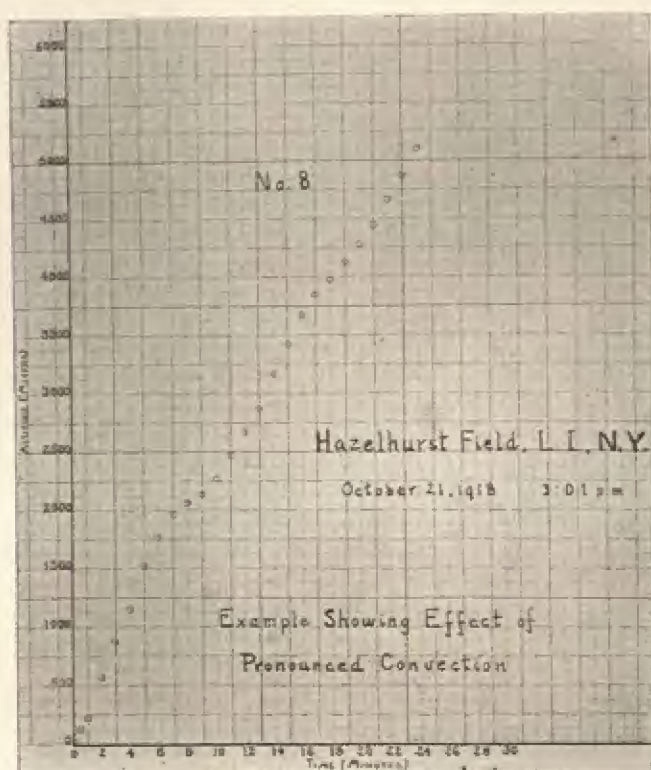


Uniform rate of ascent of pilot balloon up to 20,000 meters where balloon sprung a leak.

are desired, it is found that no accurate formula can be found for computing the speed in terms of the ascensional force, the weight to be lifted, and a single invariable constant. For approximate work, however, the one-theodolite method, because of its convenience and because of the impracticability of measuring an accurate base line at the front, is much in use, and one of the advances made in the meteorological work of the army during the past year has



consisted in developing with the aid of the large amount of data available, a general formula for the rate of ascent in terms of the ascensional force and the weight to be lifted, which though far from accurate is more reliable than that which has heretofore been used. The formula heretofore used is that of Dine's, namely,



Correction currents at low altitudes.

$$V = K \frac{l^{\frac{1}{2}}}{L^{\frac{1}{2}}},$$

in which  $V$  represents the rate of ascent in meters per minute,  $l$  is the free lift, or the weight of the displaced air less the weight of the balloon and contained hydrogen,  $L$  is the weight of the balloon plus the free lift and  $K$  is a constant.

The formula as modified by the observers of the Signal Corps is

$$V = K' \left( \frac{P}{L^2} \right)^{.208}$$

This formula is found to fit the observational data within the ranges used in the Signal Corps work to an accuracy of somewhat less than 10 per cent., which is sufficient for most work at the front.

2. *Meteorology in the Aid of the Artillery.*—In former times when guns did not shoot to a greater distance than eight or ten miles, it was usually possible to observe where the projectile hit and to correct errors by "spotting." This made unnecessary the correction of the trajectory for the influence of the wind and the changing density of the air with increasing altitude. In the present war, however, guns have been built to shoot much farther and in addition camouflage has prevented the visual location of guns even at the old ranges. Hostile batteries have been located in many instances solely by the new art of sound-ranging which has itself demanded for the high accuracy attained aërological data. The answering battery has been obliged to fire wholly by the map, so that it is obvious that it has become necessary to make careful allowances both for the density of the air and the direction and speed of the wind at various altitudes. Some of the modern projectiles remain in the air as long as seventy seconds and a moderate wind blowing across the path of such a projectile might easily cause it to drop half a mile away from the point at which it would strike if fired in still air. The wind-direction and speed at various altitudes have been obtained, as already indicated by pilot balloons, while the temperature has been determined at the proving grounds by sending self-recording instruments aloft in specially constructed box-kites, as well as by sending self-recording instruments and meteorological observers aloft in airplanes. It has been with the aid of observations of this sort that the new range tables for the Ordnance Department of the United States Army have been constructed. The importance of this work may be understood when it is considered that these range tables will be used in connection with the firing of all guns, and errors in them would produce errors in the range of every gun fired with their aid.

3. *The Development of Long Range Propaganda Balloons.*—In view of the fact that above an altitude of 10,000 feet 95 per cent. of



the winds both over western Europe and over the United States blow from west to east (*i.e.*, have a westerly component), Captain Sherry in 1917 suggested the development of a large program for the extension of the use of pilot balloons for the purpose of flooding the whole of Germany and Austria with propaganda dropped from such balloons. The project was submitted to the meteorological and military agencies in France and pronounced infeasible, chiefly because the rapid diffusion of hydrogen through rubber had heretofore rendered it impossible to obtain pilot balloon flights of more than about 100 miles. Undiscouraged, however, by these reports, Mr. W. J. Lester, Dr. S. R. Williams and Sergeant Redman attacked the problem of extending the range of pilot balloon flights by developing an automatic ballast-control and by reducing the diffusion by means of a special dope.

The automatic control was ingeniously simple, its essential feature being a belly band which kept the girth of the balloon constant (at a diameter of four feet) through the discharge, in the act of shrinking, of a few drops of kerosene, thus causing reascension and consequent expansion.

With this device the balloon not only does not fall but rises very gradually to higher and higher levels until its ballast of kerosene or alcohol is exhausted.

In the week beginning October 3, 1918, sixty such balloons, adjusted to fly between the initial and final altitudes of 15,000 and 25,000 feet respectively were sent up from Fort Omaha, Nebraska, carrying return cards and watches, which were arranged to stop and be let down on small parachutes as soon as the ballast was exhausted. Thirty-four out of sixty of these balloons were picked up and returned to Washington. Instead of flying 100 miles, one of them came down within ten miles of New York, 1,100 miles from Fort Omaha, another was returned from Virginia, 930 miles from its starting point, and the rest were scattered over Ohio, Kentucky, Illinois, Wisconsin and Iowa. Not one went west of Omaha though the balloons were sent up on days on which different surface conditions prevailed.

The credit for this achievement, the significance of which will be discussed later, is due primarily to Mr. Lester, Captain Sherry,

Dr. Williams and Sergeant Redman. At the time of the signing of the armistice the Military Intelligence Service was preparing for the extensive use of these balloons for flooding the whole of Germany, Austria and even parts of Russia with suitable leaflets, several hundred of which could have been scattered by a single balloon, the total cost of which would have been but two or three dollars.

TABLE I.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Ellendale, N. D. (90th Meridian Time.)

*Wind Aloft Report.*

Time 7:00 A.M.

Date November 13, 1918.

Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.	Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.
0	SW	29		5,250	NW	57	
250	S	17		5,500	NW	60	
500	SW	16		5,750	NW	59	
750	SW	15		6,000	WNW	63	
1,000	W	15		6,250	NW	69	
1,250	W	16		6,500	NW	68	
1,500	WNW	18		6,750	NW	68	
1,750	WNW	19		7,000	NW	74	
2,000	WNW	22		7,250	NW	77	
2,250	WNW	25		7,500	NW	85	
2,500	WNW	27		7,750	NW	65	
2,750	WNW	34		8,000	NW	73	
3,000	WNW	35		8,250	NW	76	
3,250	NW	35		8,500	NW	69	
3,500	NW	40		8,750	NW	75	
3,750	NW	41		9,000	NW	73	
4,000	NW	41		9,250	WNW	74	
4,250	NW	47		9,500	WNW	68	
4,500	NW	53		9,750	WNW	65	
4,750	NW	56		10,000	WNW	78	
5,000	NW	54		10,250	NW	81	

4. *The Charting of the Upper Air in Aid of Aviation.*—In a recent Brisbane editorial the following sentence occurs: "Flying machines of the future going long distances will travel at least 32,000 feet up, where no wind blows except the gentle eastern wind caused by the earth's motion on its axis." It is quite likely that the future aviator will fly high, but his motive will be to find an air current, not to escape one. The gentleness of the zephyrs existing at high altitudes may be seen from tables 1, 2, 3, 4 and 5 which record three sets of pilot balloon observations recently taken by the Signal



Corps. These tables show air currents increasing in intensity with increasing altitude and approaching the huge speed of 100 miles per hour. Such speeds are perhaps exceptional, but not at all un-

TABLE II.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Groesbeck, Texas. (90th Meridian Time.)

*Wind Aloft Report.*

Time 7:00 A.M.

Date November 1, 1918.

Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.	Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.
0	E	9		6,750	WNW	25	
250	ESE	16		7,000	WNW	19	
500	ESE	13		7,250	W	8	
750	ESE	2		7,500	W	12	
1,000	WSW	5		7,750	W	9	
1,250	WNW	11		8,000	WSW	4	
1,500	WNW	18		8,250	WSW	16	
1,750	WNW	23		8,500	WNW	20	
2,000	NW	25		8,750	W	22	
2,250	NW	20		9,000	WSW	20	
2,500	WNW	20		9,250	WSW	20	
2,750	NW	23		9,500	WSW	22	
3,000	NNW	21		9,750	WSW	28	
3,250	N	18		10,000	W	30	
3,500	NNW	29		10,250	W	47	
3,750	NW	25		10,500	W	50	
4,000	NNW	20		10,750	WNW	59	
4,250	NW	20		11,000	WNW	57	
4,500	NW	21		11,250	W	44	
4,750	NW	20		11,500	W	39	
5,000	WNW	16		11,750	W	41	
5,250	WNW	18		12,000	W	47	
5,500	WNW	35		12,250	W	51	
5,750	WNW	35		12,500	W	56	
6,000	WNW	32		12,750	W	59	
6,250	WNW	25		13,000	W	60	
6,500	WNW	26		13,250	W	64	

known. The pilot balloon mentioned in 3 travelled from Omaha to Virginia at an *average* speed of thirty miles per hour, the average height being 18,000 feet. On November 6, 1918, at Chattanooga, Tennessee, a velocity of 154 miles an hour at an altitude of 28,000 feet was observed by one of the meteorological units of the Signal Corps.

These facts bring out the importance of a forecast of such currents for the purposes of long flights. A flier aided by such a wind

TABLE III.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Ellendale, N. D. (90th Meridian Time.)

*Wind Aloft Report.*

Time 8:26 A.M.

Date December 5, 1918.

Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.	Altitude, Meters.	Direction, Meters.	Velocity, M. P. H.	Remarks.
0	NW	19		1,750	NW	64	
250	NW	47		2,000	WNW	68	
500	NW	49		2,250	WNW	81	
750	NW	57		2,500	WNW	87	
1,000	NW	48		2,750	WNW	96	
1,250	WNW	49		3,000	WNW	93	
1,500	WNW	50					

TABLE IV.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Mineola, L. I. (75th Meridian Time.)

*Wind Aloft Report.*

Time 7:06 A.M.

Date September 7, 1918.

Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.	Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.
0	N	18		2,000	SW	25	
250	N	51		2,250	SW	37	
500	N	65		2,500	SW	63	
750	N	29		2,750	SW	55	
1,000	W	22		3,000	SW	54	
1,250	W	20		3,250	SW	55	
1,500	W	11		3,500	SW	81	
1,750	WSW	13					

as that last mentioned would move toward his objective  $2 \times 154$ , or 308 miles an hour more rapidly than if he were opposed by it. When it is recalled that the aviator above the clouds has no means of knowing anything about the motion of the air in which he flies, it will be seen that it is of the greatest importance to him to know the nature of the currents at different levels. Table 4 furnishes a very typical illustration of this importance.

From the above data it is evident that an aviator flying toward the west at this time and place should have flown at an altitude of 1,000 meters, while an aviator flying toward the east should have flown at an altitude of 4,000 meters or more.



TABLE V.

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.  
Station Fort Oglethorpe, Ga. (90th Meridian Time.)

*Wind Aloft Report.*

Time 7:39 A.M.

Date November 29, 1918.

Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.	Altitude, Meters.	Direction, Compass.	Velocity, M. P. H.	Remarks.
0	NW	7		1,750	W	36	
250	NW	8		2,000	W	41	
500	NW	11		2,250	W	46	
750	WNW	19		2,500	WSW	47	
1,000	W	29		2,750	WSW	56	
1,250	W	34		3,000	WSW	76	
1,500	W	36		3,250	WSW	96	

TABLE VI.

Altitude In Meters.	Wind Direc- tion.	Wind Velocity In Miles per Hour.
Surface.....	NW .....	2.2
500.....	E .....	5.8
1,000.....	E .....	8.3
2,000.....	NE .....	5.4
3,000.....	W .....	5.4
4,000.....	NW .....	24.6
12,000.....	NW .....	49.2

In order to meet the obvious need of the aviator for a knowledge of upper air currents the Signal Corps in the summer of 1917 undertook for the first time in history a general program of mapping the upper air currents of the United States, the Atlantic and western Europe in aid of aviation and particularly with reference to trans-Atlantic flight. By the fall of 1918 twenty-six upper air stations, carefully distributed over the United States, were in full operation in place of the one station which has existed before the war. From these stations reports are telegraphed twice daily to the Weather Bureau in Washington. From the pilot balloon observations charts are constructed showing the wind speed and direction at the various levels: for instance, one chart shows the wind direction and speed near the ground, another chart shows the wind direction and speed 500 meters above the ground and additional charts show the wind direction and speed at the following levels: 1,000, 1,500, 2,000, 3,000 and 4,000 meters above the ground. The fore-

caster at Washington has the various charts before him showing wind and weather conditions prevailing over the United States within an hour and a half after the observations are made. From these charts he prepares the forecast of weather conditions for the various sections of the United States and at the same time prepares a statement of the wind and weather conditions at various altitudes along the various air routes for the use of aërial navigation. This service is already being used by the aërial mail service, and it is also used by the military flyers, as is evidenced by telegraphic requests received at various military meteorological stations for special reports on the weather and wind conditions when long distance flights are contemplated.

The problem of exploring the upper air currents over the Atlantic was at first thought insoluble on account of the absence of fixed bases, but the success of the Meteorological Service in developing its long-range propaganda balloons has now made possible the mapping of the upper-air highways across the Atlantic, for arrangements are being made to send up both from coastal stations and from trans-Atlantic steamers these long-range balloons designed now for from two to three thousand mile flights, and adjusted to maintain a constant altitude and to drop in western Europe their records of average winds in these heretofore unchartable regions. The importance of this work for the future of aviation needs no emphasis.

The success which the Meteorological Service has attained would have been wholly impossible had it not been for the intimate and effective coöperation which has been extended to it in all of its projects by Director Marvin and the whole staff of the United States Weather Bureau. The chief credit for the work abroad should go to Major William R. Blair, commissioned from the Weather Bureau for the observational work with the A. E. F. For the success of the service in this country Captain Sherry and Lieutenant Waterman have perhaps the chief responsibility. Captain Murphy and Professor Fassig have, however, contributed very important elements.

UNIVERSITY OF CHICAGO,  
April, 1919.



## DETECTING OCEAN CURRENTS BY OBSERVING THEIR HYDROGEN-ION CONCENTRATION.

By ALFRED GOLDSBOROUGH MAYOR.

(Read April 24, 1919.)

### OBSERVATIONS.

The surface water of the middle regions of the Tropical Pacific commonly flows in a westerly direction due to the effect of the trade winds, and this water is strongly alkaline, its hydrogen-ion concentration being about 8.22 PH, or  $0.602 \times 10^{-8}$ . Occasionally, however, in the Tropical Pacific one finds a region wherein the surface water is temporarily flowing toward the east and thus counter to the trend of the usual current and of the trade winds. I find that this easterly moving water is commonly less alkaline than is that of the general region in which it occurs. Thus while the water moving toward the west is about 8.22 PH these easterly counter currents are 8.1 to 8.18 PH, or  $0.83 \times 10^{-8}$  to  $0.66 \times 10^{-8}$ .

The tension of the carbon dioxide of the great westerly current appears to about the same as that of the air above the sea ranging in our tests from 2.75 to 3.25 ten thousandths of an atmosphere, whereas the water which is moving in an easterly direction is more strongly changed with free  $\text{CO}_2$ , its tension ranging from 3.45 to above four ten thousandths of an atmosphere. Moreover, this easterly moving water is slightly colder than that of the general region in which it occurs and Professor L. R. Cary found its oxygen content was higher than normal. Thus it seems that these counter currents are caused by deep water which has temporarily appeared upon the surface either by welling upward or through a local displacement of the westerly-moving surface layer.

This suggests that eddies may be set up due to the gusty nature of the trade winds, as shown in Fig. 1. Every "puff" pushes some water ahead of it and leaves a hollow in its wake which must be filled up to the general level by deeper water rising to the surface,

and this deeper water is in turn replaced by the water which has been temporarily heaped up in front of the gust. There is nothing to prevent an under-water counter current, whereas in order to fill the hollow by surface water the current would have to move against the prevailing wind as at *a*, Fig. 1; and the friction between air and



FIG. 1.

water is much greater than that between water particle and water particle. Despite this process of local adjustment, however, the westerly trend of the surface current tends to raise the general ocean level in the western regions of the Tropical Atlantic and Pacific, and this is counterbalanced by the great oceanic surface eddies of which the Gulf Stream and the Japan Current are well known examples. The general up-welling of deep water in tropical regions has been known since the cruise of the *Challenger*.

Thus due to local causes, water from the depths of the Tropical Pacific sometimes comes to the surface in large quantity, and retains some of its easterly movement, even against the prevailing wind. Then upon being heated by the sun and mixing with the warm surface waters its capacity for retaining free  $\text{CO}_2$  is reduced, and its carbon dioxide passes out into the atmosphere.

As is well known McEwen, 1910, 1916, etc., has demonstrated from studies of salinity that great quantities of deep water are constantly welling up along the Pacific coast of America, and in confirmation of this fact I find that the  $\text{CO}_2$  tension of the surface water along the Pacific coast of the United States is considerably higher than we would expect from its low temperature, and much



above that of the water farther off the coast. Thus a PH of 7.85 at 10.5° C., and CO<sub>2</sub> tension of 5.4 ten thousandths of an atmosphere were observed 54 miles off Golden Gate, San Francisco, on May 1, 1917; and somewhat similar conditions were seen off Vancouver in September, 1918.

An up-welling of deep water due to off shore winds has also been demonstrated by Bigelow, 1917, p. 241; along the coast of New England north of Cape Cod, but this effect is neither so marked nor so constant in the shallow water along our Atlantic seaboard as it is off the abrupt slope of the Pacific coast. Indeed Bigelow, 1915, 1917, has shown that the cold water which drifts down the Atlantic coast from Nova Scotia to Florida is chiefly derived from the Gulf of St. Lawrence and receives accessions from surface drainage and from rivers along its whole course.

McClendon, 1917, 1918, showed that the CO<sub>2</sub> tension of surface water at Tortugas and in the Gulf Stream, is on the average about in balance with the atmosphere, 30 determination indicating that the pressure of carbon dioxide of the air ranges from 2.8 to 3.5 ten-thousandths of an atmosphere, while that of the surface water of the Tortugas lagoon on the east side of Loggerhead Key ranged from 2.6 to 3.5 ten-thousandths of an atmosphere, and that of the Gulf Stream from Key West to Cape Hatteras was from 3.2 to 3.5. McClendon also found that photosynthesis by marine plants in sunlight is a very important factor in controlling the hydrogen-ion concentration of the water of shallow lagoons or tide pools where the bottom is covered with sea weed; for the plants reduce the CO<sub>2</sub>, thus setting free oxygen and causing the water to become highly alkaline. For example, while the PH of the sea around the Tortugas is about 8.22 that of the lagoon rose at times to 8.35 by day and sank to 8.18 at night, and the hot shallow lagoon of the Marquesas, Florida, had a PH of 8.46 accompanied by precipitation of calcium carbonate. McClendon was, however, unable to find any appreciable diurnal range in hydrogen-ion concentration of the surface water in the open sea nor can I detect it from my studies in the Atlantic and Pacific.

Also Wells, 1918, p. 6, shows that the water of the Gulf of Mexico contains about 0.092 grams of CO<sub>2</sub> per liter and its surface

tension is thus in balance with the atmosphere, and I find that when uninfluenced by up-welling of unusual quantities of deep water the  $\text{CO}_2$  tension of the surface waters of the Tropical Atlantic and Pacific is also practically in balance with the atmosphere.

Thus on the voyage of the S. S. *Niagara* from Fiji to Honolulu, September 6 to 12, 1918, we encountered only the prevailing westerly set uninterrupted by any currents moving toward the east, and the average PH was about 8.22, the average temperature  $28^\circ \text{C}$ ., and the  $\text{CO}_2$  tension of the water three ten-thousandths of an atmosphere and thus practically the same as that of the air. When cold deep water wells upward to the surface, however, a different condition ensues, for due to relief of pressure and increase in temperature this water must discharge its excess  $\text{CO}_2$  into the atmosphere.

Thus on the voyage of the S. S. *Sonoma* between Honolulu and Pago Pago, Samoa, June 25 to 30, 1918, we at times met with strong currents set toward the east and the average PH was about 8.19 and the  $\text{CO}_2$  tension of the surface water 3.26, the average temperature being  $28^\circ \text{C}$ ., as on the voyage of the *Niagara*. Similarly on the voyage of the S. S. *Ventura* from Pago Pago, Samoa, to Honolulu on April 19 to 25, 1917, we met with several strong sets to the eastward and the average PH was 8.17, the  $\text{CO}_2$  tension 3.35 and the temperature  $25.7^\circ \text{C}$ .

Henderson and Cohn, 1916, p. 621, conclude from laboratory experiments that upon the whole in most places and at most seasons carbon dioxide must be escaping from the sea into the air, although they also state that the balance is doubtless restored by  $\text{CO}_2$  entering the water from the air in the polar regions. These authors did not consider the effect of photosynthesis by marine plants which McClendon afterward showed to be such an important factor. Were it not for photosynthesis it is probable that large quantities of carbon dioxide would escape from the sea in the tropics, but instead of this McClendon, Wells and I find that the warm waters are practically in balance with the atmosphere.

My observations along the Atlantic coast between Nova Scotia and Florida in December–March show also that the coastal current during these cold months has a  $\text{CO}_2$  tension somewhat below that of the atmosphere, and this may be due to the great concentration of plant life in these cold waters.



Thus according to my observations the averages for the shore current the salinity of which ranges from 30 to 33 grams in 1,000 grams of water, between Nova Scotia and northern Florida in winter are: Temperature  $6.7^{\circ}$  C., salinity 31.7, PH 8.05 and  $\text{CO}_2$  tension 2.5 ten-thousandths of an atmosphere, while similar data for the Gulf Stream of salinity 36 at the same season between the Straits of Florida and Cape Hatteras are: Temperature  $22.3^{\circ}$  C., salinity 36.35, PH 8.21, and  $\text{CO}_2$  tension 2.77. Thus the cold shore water seems to be in a condition to absorb  $\text{CO}_2$  from the air, while the warm Gulf Stream waters are more nearly in balance with the atmosphere. In summer when the shore current is warmed to about  $22^{\circ}$  C., its  $\text{CO}_2$  tension rises to be quite in balance with the atmosphere, as is indicated by McClendon's Table VII., p. 226, 1918.

It is well known from the extensive work of Blackman and Smith that photosynthesis about doubles in effect for  $10^{\circ}$  C. rise in temperature, but due to the action of denitrifying organisms such as Drew's *Pseudomonas calcis* the tropical waters are deprived of nitrogen and can thus support only a meager plant life in comparison with that of colder regions. Thus McClendon found less than 0.01 mg., of nitrogen per liter as nitrates and nitrites at Tortugas, Florida, while Raben, 1910, found more than ten times these amounts in the North Sea; and as shown by McClendon the tropical ocean despite its high temperature can only eliminate a small part of its free  $\text{CO}_2$  by photosynthesis due to the scarcity of plant life.

Krog, 1904, calculated that if the average  $\text{CO}_2$  tension of the ocean is the same as that of the air (about 0.0003 atmosphere), it must contain twenty-seven times as much  $\text{CO}_2$  as the air. Thus if the ocean gave off one tenth of its  $\text{CO}_2$  to the air the carbon dioxide tension of the sea would sink to 0.0002 atmosphere. He found that the  $\text{CO}_2$  in the air of Disko Island, Greenland, ranged from 0.00025 to 0.007, being high with winds from the north and west, and low when the wind blew from the south and east. The turbid sea water at Disko Island had a  $\text{CO}_2$  tension of 0.0001 to 0.00035, while the clear water in the same region had a tension of 0.00035 to 0.0006 atmospheres, thus apparently being lower than that of the surrounding air.

Also the  $\text{CO}_2$  tension of the surface water between Cape Fare-

well, southern Greenland and the Shetland Islands was distinctly lower than that of the air.

The average  $\text{CO}_2$  tension of the air over the ocean seems to be about 0.000295, this being the mean of 51 observations made by Thorpe between Brazil and England. In 1917, however, using apparatus given to me by Professor McClendon, I tested the  $\text{CO}_2$  tension of the air over the Pacific between Samoa and San Francisco, but there was apparently no relation between the local  $\text{CO}_2$  tension of the air and that of the water under the air, this lack of coördination being due in all probability to the great mobility and rapid fluctuation in  $\text{CO}_2$  tension in the air as compared with that of the water. It would apparently be necessary to obtain several thousand determinations of the  $\text{CO}_2$  tension of air over the ocean taken at all seasons and in all weathers to determine its mean  $\text{CO}_2$  tension with accuracy, but the determinations that have been made indicate that it is not far different from that of the air over the land. My average for three voyages over the Tropical Pacific is: Temperature  $27.5^\circ$ , PH 8.22, and  $\text{CO}_2$  tension 3.15 ten thousandths of an atmosphere. Thus the tropical waters appear to have a  $\text{CO}_2$  tension slightly above that of the atmosphere.

We lack sufficient data for a definite statement as to whether  $\text{CO}_2$  is on the whole passing from air to sea or *vice versa*, but the surmise may seem reasonable that a balance is maintained; the absorption of  $\text{CO}_2$  from the air by the Polar Seas being offset by its passing out of the ocean over the wide area of the tropics, while the temperate regions stand in an intermediate relation, the water absorbing  $\text{CO}_2$  during the winter and giving it out to the air during the summer.

It may be of interest to compare our observations with those of Palitzsch, 1911, who was the first to apply Sørensen's colorimetric methods to the study of the hydrogen-ion concentration of sea water.

Palitzsch used naphtholphthalein and phenolphthalein as indicators and tested the PH of the Black Sea, Sea of Marmora, Mediterranean, Atlantic and North Sea in summer with the following results:



Locality.	PH of Sea Water.
Black Sea { surface .....	8.34
{ deep water .....	7.45
Sea of Marmora and Bosphorus .....	8.35
Eastern Mediterranean .....	8.27
Western Mediterranean .....	8.22
Coast of Portugal .....	8.25
Off Scotland and Faroe Is. ....	8.08-8.22
S.E. part of North Sea and Skagerak .....	8. -8.05

## METHODS.

The hydrogen-ion concentration of sea water was tested by the simple process of placing 0.4 c.c. of  $\frac{1}{10}$  of 1 per cent. thymolsulphonaphthalein in a non-soluble glass test tube of 24 mm. caliber and adding 30 c.c. of the sea water to be tested. Highly alkaline sea water gives a blue-green solution, while relatively acid water gives a greenish-yellow color. Then by comparing this test tube with a series of sealed tubes of similar caliber containing mixtures of borax, boracic acid and sodium chloride of various known hydrogen-ion concentrations we can at once determine the concentration of our sample sea water with an error of not more than 0.025 PH.

McClendon, Gault and Mulholland, 1917, were the first to standardize sodium borate and boracic acid mixtures for use in measuring the hydrogen-ion concentration of sea water with thymolsulphonaphthalein as an indicator. Their solution consists of 0.075 m. sodium borate (28.67 grams of  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ ), and 19 grams of sodium chloride, dissolved in water so as to make up 1,000 c.c. of solution. The other solution consists of 0.3 m. boric acid (18.6 grams of  $\text{H}_3\text{BO}_3$ ) and 22.5 grams of sodium chloride dissolved in water so as to make up a liter of solution. Definite mixtures of these two solutions give correspondingly definite hydrogen-ion concentration, as is shown by McClendon, Gault and Mulholland, p. 44, 1917.

Professor McClendon kindly gave me a set of these tubes which I have used on voyages to test the hydrogen-ion concentration of the surface water of the ocean. The readings of these tubes were compared with those of a Leeds and Northrup potentiometer standardized by the U. S. Bureau of Standards. McClendon thus tested their accuracy in 1917 and I repeated the process in April, 1919,

and found that the colors of the tubes, which had been carefully guarded from light when not in use, had not change in the interval.

As is well known the unit of hydrogen-ion concentration is 1 normal hydrogen-ion per liter of water, or about 1 gram of hydrogen-ion per liter. The purest distilled water contains only about 1 gram of hydrogen-ion in 10,000,000 liters of water at about 22° C., and thus its hydrogen-ion concentration is about  $10^{-7}$ . Sea water, however, is alkaline and contains only about one tenth this concentration of hydrogen-ions, or as we say its hydrogen-ion concentration is about  $10^{-8}$ .

In order to avoid writing negative exponents Sørensen, 1909, p. 28, devised the symbol "PH" to indicate the negative logarithm of the hydrogen-ion concentration. Thus according to Sørensen's system a normal hydrogen-ion concentration, or  $10^0$  of H-ions per liter, is written PH 0; a decinormal H-ion concentration, or  $10^{-1}$ , is PH 1; while sea water with somewhat less than 0.000,000,01 normal hydrogen-ion concentration is about  $10^{-8}$  normal and is designated 8 PH.

If for example a specimen of sea water had a hydrogen-ion concentration of

$$\frac{1}{1.622 \times 10^8} = 0.616 \times 10^{-8},$$

we would call its PH 8.21 because 0.21 is the logarithm of 1.622, and 8 is the logarithm of  $10^8$  and  $0.21 + 8 = 8.21$ .

McClendon's borax-boracic colorimetric tubes indicate the true PH of sea water containing 32 to 33 grams of total salts per 1,000 grams of sea water (salinity .32 per cent. to .33 per cent.), and the following table gives the correction which McClendon found must be applied in order to find the true PH of sea water of any other salinity:

Salinity of Sea Water in Grams of Total Salts per 1,000 Grams of Water.	Correction to be Applied to the Reading of the Colorimetric Tube to Find the True PH of the Sea Water.
30 .....	+ 0.02
31 .....	+ 0.01
32-33 .....	+ 0.
34 .....	- 0.01
35 .....	- 0.02
36 .....	- 0.03
37 .....	- 0.04



The carbon dioxide tension of the sea water was calculated from the true PH and the temperature according to the ratio determined experimentally by McClendon, 1917, p. 36. McClendon found that the PH of sea water normally declines .01 for 1° C. decline in temperature. Thus if the PH is 8.22 at 28° it may be expected to be 8.21 at 27° C. I find this to be true under normal conditions, but if the sea water is diluted with river water rich in CO<sub>2</sub> or mingled with large amounts of up-welling water from the depths, this relation may even be reversed. Thus in the Tropical Pacific I have observed a *rise* of 0.13 in the PH while the temperature sank 0.45° C. In general, however, under normal conditions, McClendon's rule holds good both for the Atlantic and the Pacific.

The salinity of the sea water is expressed in grams of total salts per 1,000 grams of water, and was determined by titration with AgNO<sub>3</sub>, using K<sub>2</sub>CrO<sub>4</sub> as indicator, and standard sea water obtained from Professor Martin Knudsen for comparison.

The thermometers read to 1/10° C. and were compared with a thermometer standardized by the U. S. Bureau of Standards.

The currents were determined by the drift of the ship from her expected position. Naturally only a decided current could be detected by this crude method, but it was the only one available. The sea water was dipped up in a glass vessel from the stern of the vessel and tested at once for hydrogen-ion concentration and temperature, and a sample was preserved for determination of salinity. Experiments showed that no contamination from the ship could be detected if the water were dipped up from the stern rather than from the bow, waste from the sides of the ship being forced away from the stern by the back wave of the wake.

#### SUMMARY.

Through the simple process of placing a few drops of the red dye thymolsulphonaphthalein in the bottom of a test tube and filling the tube with sea water we can determine its hydrogen-ion concentration. The more alkaline the water the more blue-green the color while relatively acid water gives a yellowish-green color.

In the Tropical Pacific the surface water drifting toward the

west is decidedly alkaline, about 8.23 PH, and its carbon dioxide tension is about 0.0003 atmospheres, and thus about in balance with the air. Back set currents moving in an easterly direction are, however, often encountered in the equatorial mid-Pacific especially in about 5° north latitude. This water is somewhat cooler than that of the prevailing westerly current, its carbon dioxide tension is decidedly acid, ranging from about 8.1 to 8.18 PH. Thus it comes from depths wherein the water is at least from 5° to 13° C. colder than the temperature of the surface of the ocean, and therefore from at least 100 to 200 fathoms beneath the surface (see chart No. 19, "Narrative of *Challenger* Expedition," Vol. 1, part 2, p. 758).

The gusty character of the trade winds combined with the general up-welling of deep water in the equatorial region may be a primary cause of this easterly current which consists of deep water that has come to the surface.

My conclusions support those of McClendon that the PH of sea water is dependent chiefly upon the temperature, and not upon the salinity of the water. A fall of 1° C. in temperature normally corresponds with a decline of about 0.01 in the PH as found by McClendon, but this may be altered by local conditions, such as dilution by relatively acid fresh water, or by the coming to the surface of cool deep water heavily charged with CO<sub>2</sub> which it discharges into the atmosphere upon being heated.

The cold shore current along the Atlantic coast of America between Nova Scotia and Florida is relatively acid in comparison with the Gulf Stream, being 7.9 to about 8.1 in winter, and its carbon dioxide tension is lower than that of the air, due possibly to photosynthesis maintained by its abundant plant life. It is thus absorbing carbon dioxide from the air. Thus the colder surface waters are absorbing carbon dioxide, while the tropical regions are probably setting it free into the atmosphere.

The detection of the sudden and marked change from blue-green to yellow-green when one encounters an easterly set in the Tropical Pacific, or passes from a warm into a cold current, can be so easily made that this method may prove of value in navigation.



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# RECENT DISCOVERIES OF FOSSIL VERTEBRATES IN THE WEST INDIES AND THEIR BEARING ON THE ORIGIN OF THE ANTILLEAN FAUNA.

BY W. D. MATTHEW.

(Read April 25, 1919.)

## INTRODUCTION. INTEREST OF WEST INDIAN FOSSILS—REVIEW OF EARLIER KNOWLEDGE.

Ten or twelve years ago almost nothing was known of the extinct vertebrates of the West Indies. There was good reason to suppose that a considerable fauna had existed, and that if found it would be a very interesting one. One would expect to find peculiar insular types, different from the mainland faunas, and the affinities of the various types would provide evidence as to former land connections and other interesting problems. The modern fauna of the islands has undoubtedly been greatly modified by man, both before and since its settlement by white men. Such indigenous mammals as existed have mostly disappeared in consequence, and with them many of the lower vertebrates and invertebrates. And many animals have been introduced either by intention or by accident. *Capromys*, *Plagiodontia* and *Solenodon*, two peculiar rodents and a very peculiar insectivore, are the only surviving mammals that are certainly indigenous. The lower vertebrates are more numerous, but many of them also have been exterminated, and others introduced since man arrived on the islands.

The climate and geology of the islands limit the prospects of discovery of fossil land faunas to cave and stream or spring deposits of Pleistocene age. The underlying sedimentary formations are practically all marine, chiefly Tertiary limestones and an older metamorphosed series which seem to be chiefly altered volcanic ma-



terial. The freshwater and littoral sediments of continental areas are unknown in the West Indies, even in the larger islands (with one or two unimportant and doubtful exceptions) and it is from these that our fossil records of land animals are almost wholly derived. There was, and is, therefore, very little prospect of discovering remains of the Tertiary or pre-Tertiary land faunas of the West Indies. The possibilities are practically limited to the Pleistocene.

Up to a few years ago two important discoveries had been made. One was the giant rodent *Amblyrhiza* found in cave-breccia on the island of Anguilla, and described by Cope in 1869. The affinities of this animal, about the size of a capybara, have been disputed, Cope regarding it as allied to the South American chinchillas, while J. A. Allen considered it as a relative of the extinct *Castoroides* or "giant beaver" of North America. Dr. Allen's view, although mistaken, seems to have been more generally accepted. The other discovery was a ground-sloth jaw and some other remains found near Cienfuegos in Cuba, and described by Dr. Leidy under the name of *Megalocnus*, as a near relative of the North American ground-sloth *Megalonyx*. For reasons that I shall explain later the Cuban discovery was little known and more or less discredited in scientific discussion. The *Megalocnus* was supposed to be identical with *Megalonyx*, but many doubted whether the specimen really came from Cuba. Such as it was, the evidence from fossils seemed to point strongly to a land connection with North America as late as the Pleistocene, extending at least as far as Anguilla. This no doubt played its part in the very prevalent belief in an Antillean continent, united with the greater continents to north and south of it, destroyed only in times geologically very recent.

The characters of the modern Antillean faunas were very difficult to reconcile with this hypothesis. Their insular character is very marked, whatever theories might be entertained as to the origin of the various animals. And what was known of the geology did not at all accord with the view that they were fragmented remnants of a great continent recently broken up. A diligent search for fossil remains and a more thorough and systematic study of the geology was very much needed.

## THE PORTO RICO DISCOVERIES.

With these and other considerations in mind, the New York Academy of Sciences decided in 1913 to undertake a systematic survey of the geology and natural history of Porto Rico, in coöperation with the local government and with the American Museum of Natural History. This was very ably conducted under direction of Dr. Britton. The geology was quite thoroughly investigated by Drs. Berkey, Reeds and others and the reports afford a better knowledge and understanding of the geologic history of this island than we have of any of the others. The marine limestone yielded one interesting fossil mammal, a sirenian or sea-cow allied not to the manatees as one would expect, but to the old-world dugongs.

The most important find in the way of land animals was made in the course of investigations in a cave near Utuado, where human remains probably prehistoric were unearthed, and beneath them remains of several kinds of extinct mammals. This stimulated further search of the numerous caves in the island, undertaken by Mr. Anthony for the American Museum of Natural History, and the results of his very successful work have been published in a well-illustrated memoir issued last December.

The fossil mammals include one insectivore, one edentate and a number of rodents, all new and very peculiar types, widely different from any known animals; also a number of bats closely allied to the living bats still on the island. Most of this fauna is represented by well-preserved skulls and various bones of the skeleton.

The insectivore *Nesophontes* is so distinct that it has to be placed in a family by itself. It has some distant affinities with the Soricoida (moles and shrews), but is a very primitive type, and its nearest allies are perhaps to be found among the Eocene insectivora of North America. There is no suggestion of relationship to *Solenodon*, the only other known insectivore of the West Indies, nor to the extinct *Necrolestes* of South America, the only insectivore belonging to that continent. Like the Eocene insectivores it retains a great deal of the primitive tri-tubercular type of dentition which nearly all—if not all—the primitive mammals once possessed.

The edentate, *Acratocnus*, is not less interesting. The skull is superficially much like the two-toed tree sloth *Cholæpus*, with the



same type of triangular tusks and is of quite moderate size. Its nearer affinities, however, are with the great extinct ground sloths. It belongs to the same family as *Megalonyx* of the North American Pleistocene, but is not very closely related to it, and is very much smaller and in some respects more primitive. Although thus related to a North American genus of ground sloths *Acratocnus* points to a South American origin, for *Megalonyx* is known to be an immigrant type in the north, derived from South American ancestors in the Miocene.

The rodents all belong to the Hystricomorph or porcupine section of this order, which has its headquarters in South America.

The largest of them, *Elasmodontomys*, is closely related to *Amblyrhiza*, the gigantic extinct rodent of the island of Anguilla. Another smaller genus, *Heptaxodon*, also belongs in this neighborhood, but is less closely related. These are put into the family Chinchillidæ, but their nearest affinities are with the extinct *Megamys* and *Tetrastylus* of the Pliocene of Argentina.

A second group of rodents, *Heteropsomys* and *Homopsomys*, is related, but rather distantly, either to the living agouti, *Dasyprocta*, or the spiny rats of South America; it has also, as will appear, some extinct relatives in Cuba and Hayti.

A third extinct rodent from Porto Rico, *Isolobodon*, is nearly related to *Plagiodontia*, an extinct or almost extinct rodent of Hayti, and more distantly to the hutias (*Capromys*) still living in Cuba and Jamaica. Like the preceding group it is rather distantly related to any continental rodents; it is referred to the Octodontidæ.

That is the full extent of the mammal fauna of Porto Rico. Its affinities are chiefly South American, but distant, pointing to long isolation. The near relationship to the extinct Anguillan rodent is significant. The bank of shallow water which extends eastward from Porto Rico includes the Virgin Islands; and Anguilla with the adjoining islands also stands on a shallow bank of considerable extent. Vaughan has shown the probability of part or all of these banks being above water in the Pleistocene. But between the Virgin Islands and the Anguilla group there is a narrow trench of very deep water. Possibly this trench is due to faulting of recent origin and the islands were connected in the Pliocene or Pleistocene. The

alternate is to suppose that *Amblyrhiza* is a gigantic descendant of some small rodent that got drifted over the intervening sea barrier. Anguilla, it must be remembered, is but a small remnant of an island of very considerable size, as indicated by the extent of the surrounding shallow bank.

THE CUBAN DISCOVERIES—CIEGO MONTERO—CASIMBA—CAVE  
FOSSILS. THE FAUNA—INSECTIVORA—EDENTATA—RO-  
DENTIA—REPTILIA.

*Ciego Montero.*—The first discovery of fossil mammals in Cuba was made in 1860, in the early days of American palæontology. A lower jaw was found in a warm spring at Ciego Montero, a few miles from Cienfuegos, with other fragmentary fossils. This jaw was exhibited at the Paris Exposition in 1867, and is now, I believe, at Madrid. A drawing of it was sent to Joseph Leidy, who immediately recognized it as a relative of *Megalonyx* and named it *Megalocnus rodens* on account of the peculiar position of its tusks which simulated those of the rodents. In 1865, 1871 and 1875 De Castro published articles on extinct animals in Cuba, in which he figured this jaw and also described supposed fossil remains of *Equus* and *Hippopotamus*, and contended that these proved that Cuba had formerly been a part of the North American continent. These associates unfortunately tended to discredit the whole paper, especially the hippopotamus tusks. They did not appear to be very old, and were regarded as probably post-Columbian. The *Megalocnus* jaw was confused with the true *Megalonyx* and the suggestion was made that it was probably brought over from Central America.

Carlos de la Torre, professor of zoölogy at the University of Havana, was well aware that the *Megalocnus* had really been found in the Ciego Montero spring, and from time to time, as his duties permitted, made further investigations to see if something more could not be found at this locality or elsewhere. He succeeded in finding a few additional specimens here and better material at some other localities, and in 1910 published a notice of these discoveries. The specimens were exhibited by him at the International Congress at Stockholm and Gratz, and were deposited at the American Museum for further study and full publication in a memoir by de La



Torre and myself. The following year Mr. Barnum Brown, on Professor de La Torre's invitation and with his aid, made a more thorough exploration of the Ciego Montero spring, and secured a large collection. In 1918 Mr. Brown completed the exploration of the deposits around the spring, securing much additional material. Preliminary notices of these collections have been published, the full descriptions being postponed until all the available material had been secured. The exploration of the deposit was a rather difficult matter as the spring is a powerful one and the water had to be pumped out and drained away by means of a gasoline pump, and the spring openings cemented up, before the deposit around it could be thoroughly explored.

The Ciego Montero collections consist chiefly of bones of *Megalocnus* and *Crocodylus*, plates of a giant tortoise and a terrapin, and a few remains of other ground sloths, of rodents, lizards and birds, and a good many bones of small amphibians.

*The Casimba*.—Another important locality discovered by Dr. de La Torre was in the Sierra de Jatibonico, in the central part of the island, a fissure-spring at the bottom of a ravine where there was a considerable deposit with fossil bones. These correspond with the remains found at Ciego Montero, except that the smaller ground sloths were relatively more common. The material is equally well preserved, but not nearly so much of it. This locality has also been worked out.

A number of similar fissure springs were examined by Dr. de La Torre and a few fragmentary fossils secured, but nothing of importance. Probably deposits of this character may be discovered in other parts of the island, and some further discoveries may be made in this way.

*Cave Deposits and Kitchen Middens*.—There are also many caves in the limestone formations of Cuba, in all parts of the island. A considerable proportion of these contain guano or similar phosphatic deposits which have for many years been dug out and used for fertilizer. A few of them have recently been explored for fossils, and some very interesting material secured. The old Indian kitchen-middens, some in the caves, some elsewhere, have been more or less exploited for prehistoric human remains by the anthro-

pologists, and incidental to this work a few remains of extinct animals have been secured and described by Dr. Gerrit S. Miller, of Washington. Dr. Glover M. Allen has also published a note on some interesting cave fossils secured by Dr. Thomas Barbour. The largest cave collection yet secured was made by Mr. Barnum Brown last winter in a deposit discovered by Dr. Barbour and explored by us on his invitation.

These cave faunas consist chiefly of the remains of the small animals, rodents, insectivores, bats, etc., which are rare in the spring faunas. Remains of the ground sloths are rare, but they do occur.

Quite recently Mr. Harrington, in exploring certain caves at the far eastern end of the island for the Museum of the American Indian, secured some remains of extinct animals that warrant further search. They were chiefly *Megalocnus*, showing that this animal ranged through the whole of Cuba in the Pleistocene.

The fauna of these cave and spring deposits is a very interesting one. Fortunately the two supplement each other, so as to give a pretty full representation both of the large and of the small animals. Each consists of many hundreds of jaws, with a proportionate number of other bones. It is fair to conclude that it gives us a pretty good line on the characteristic mammals of the Cuban Pleistocene. Further discoveries may bring other animals to light, but as the same types recur in each deposit, common in one, rare in another, it does not seem likely that they will make any great additions to the fauna save through genus—and species—splitting, analogous to what has been going on among modern mammals for the last few decades. For obvious reasons it is better for palæontologists to be conservative in this respect—even at the risk of being stigmatized as “lumpers.”

*Insectivora*.—The existing *Solenodon* has not been found fossil. This is not surprising, as it is very rare now, and may have been rare during the Pleistocene. The extinct *Nesophontes* of Porto Rico is represented in Cuba by a much smaller species distinct in various particulars. It has been described by Dr. G. M. Allen as *Nesophontes micrus*. Mr. Brown secured a great series of jaws, etc., of this species in his cave collection, but only a single jaw and a tooth at Ciego Montero.



*Edentates*.—The edentates are all ground sloths related to *Megalonyx*, but belong to four distinct genera. The largest and most abundant is *Megalocnus*, about the size of a black bear. The tusks are flattened into a meniscus cross-section, and set near together, especially in the lower jaw, so that it has a curiously rodent-like effect. The cheek teeth are exceptionally long, and in consequence the palate is depressed below the level of the cranium, and the jaw extremely deep. This is like the gigantic *Megatherium*, but the form of the cheek teeth is almost exactly as in *Megalonyx*. Detailed comparisons show that the Cuban genus is most nearly related throughout to *Megalonyx*.

*Mesocnus* is a smaller and more primitive genus, which is about the size of the Miocene ground sloths of Patagonia, and like them has a long tongue of bone projecting forward between the tusks. The cheek teeth are not so long in this genus, but they have almost the same form as in *Megalocnus* or *Megalonyx*, different from the more primitive form of the cheek teeth in all the Miocene *Megalonychidae*. The tusks are rather small and not so broad or meniscoid in section as in *Megalocnus*. On the whole this is a more primitive genus, except the humerus, which has lost the entepicondylar foramen, as in *Megalonyx*.

*Miocnus* is of about the same size as *Mesocnus* but quite distinct. It is very closely related to *Acratocnus* of Porto Rico, perhaps the same genus. It has a short wide jaw and stout triangular tusks with a short, bony tongue between.

*Microcnus* is the fourth genus of ground sloths, an animal about the size of a cat, smaller than the living two-toed sloth. It resembles *Megalocnus* in the form and position of the tusks, but the molars are not so long-crowned and differ considerably in form, with a marked suggestion of the square cross-section of the *Megatheriidae*. I have not seen the skull or upper teeth; a couple of foot bones doubtfully referred to this genus come nearer to the living tree-sloths in proportions than they do to any of the large ground-sloths. It would be very interesting to know more about this little animal.

There is so much individual and age variation in ground sloths that it is difficult to say how many species of these genera are pres-

ent. *Megalocnus* occurs abundantly both at Ciego Montero and the Casimba, but apparently only one species at Ciego Montero, while at the Casimba there may be two or three. The species found at the eastern end of the island agrees better with the Casimba forms than with the Ciego Montero species. Of the smaller forms there are clearly two species of *Mesocnus*, but I see no proof of more than one of *Miocnus* or *Microcnus*.

All these Cuban ground sloths, along with the Porto Rican genus, are most nearly related to *Megalonyx* among the continental genera, and may be regarded as co-descendants with it of *Eucholæops* and *Megalonychotherium* of the Patagonia Miocene. *Microcnus* is apparently the least closely related; and the relations between *Miocnus* and *Acratocnus* are very close.

*Rodentia*.—The fossil rodents are all hystricomorphs related to the South American rodents, but not closely related. There are two groups of them (in a broad sense) each with two or three species. One is still common on the island, the Hutias with two very closely related genera, *Capromys* and *Geocapromys*. Of these *Capromys* is common in the latest cave deposits, but in the older levels of the cave material only *Geocapromys*. The species in the older levels are all small—some are smaller than any surviving species. The large species appear only at the top. The other group is entirely extinct; it consists of three or more species apparently of a single genus which Mr. Miller has called *Boromys*. It is related to the spiny rats of South America, but not closely. *Capromys* on the other hand has a near relative in Venezuela *Procapromys*.

None of the Chinchillidæ of the eastern Antilles have been found in Cuba.

Remains of *Geocapromys* occur rarely in the Ciego Montero and Casimba collections; they are very abundant in the cave collections. *Boromys*, although common in the caves, has not been found at the Casimba or Ciego Montero. Dr. Barbour tells me that there is some reason to believe that this genus still survives in Cuba, although it has not found its way into any scientific collections.

*Reptiles*.—In the Ciego Montero collection is a series of fine skulls of crocodiles, which Dr. Barbour regards as all growth stages of the living Cuban crocodile *C. rhombifer*. This species has a



broad head, and in some other characters approaches the alligator. It is closely allied to the alleged Central American species *C. moreletii*.

The most interesting of the reptiles is a giant tortoise resembling in several respects the living species of the Galapagos islands. It has a very thin shell, like most of the species of oceanic islands, but aside from this, which is probably due to parallelism, it shows some other points that are suggestive of a true relationship, although not a close one. It has one or two points suggestive of relationship to the South American tortoise *T. tabulata*, but mostly differs widely from it. Comparison with the fossil tortoises of the North American Tertiary does not indicate any special relationship, although it may be regarded as a descendant of some species of this group. It has one very curious character, unique in so far as I have made comparisons, in that the margins of the horny shields are marked on the plates not by furrows but by sharp, raised crests over the greater part of the carapace. This alone would forbid any close relationship with any of the species I have compared.

Leidy named this species *Testudo cubensis* in 1868, from a broken plate of the carapace that had been sent to him.

The terrapin is probably identical with the living Cuban terrapin, which is regarded by some as a distinct species, by others as a subspecies of the yellow-bellied terrapin *Chrysemys* (or *Trachemys*) *scripta* (= *scabra*) of the southeastern states. It is at all events closely related, and belongs to a group which has several fossil representatives in the Pleistocene of Florida and other states of the southeast.

Some fragmentary remains of lizards, snakes, birds and amphibians occur in the collections, but have not yet been studied. I doubt whether very much of interest can be got from them, as they seem to be very doubtfully identifiable.

Hayti, Jamaica and the smaller islands are as yet unexplored territory. Except for the *Amblyrhiza* of Anguilla and a few fragments described by Dr. Miller from an Indian kitchen midden at S. Pedro de Macoris, in Hayti, nothing is known of their extinct fauna. Limestone caves are numerous, and will undoubtedly furnish important finds in the near future. A primitive sirenian, *Pro-rastomus*, was described many years ago by Richard Owen from the

older Tertiary marine limestones of Jamaica. It is distantly related to the manatees, but it throws no light upon the problems here considered, and may be passed over without discussion.

REVIEW OF THE FAUNA AN NOW KNOWN. ITS INCOMPLETE AND  
INSULAR CHARACTER. UNIFORMITY THROUGHOUT THE LARGER  
ISLANDS. PROBABLE DERIVATION OF THE SEVERAL GROUPS.  
METHODS OF COLONIZATION.

So much for the new discoveries. We may now review the fauna as a whole, living and extinct, and consider its general character and what bearing it has upon the past history of the islands. I shall deal principally with the mammals, partly because I am best acquainted with them, partly because the new discoveries are chiefly in this group, and partly because I think they afford the best evidence upon certain critical points.

The most obvious features to me in the mammal fauna are its incompleteness and insular character. There are no perissodactyls, no artiodactyls, no proboscideans, no carnivora, no primates, no marsupials, no rodents except three groups of the Hystricomorphs which are an especially South American group, no insectivores save for two types which have very remote affinities to any living groups, none of the various types of edentata, except a single group of ground sloths. Certainly this poverty of mammalian fauna is not to be explained by scantiness of material. We have very large collections, many hundreds of jaws and a due proportion of other bones, from two types of deposit, a cave and a spring fauna. Correspondingly large collections from cave or spring faunas in North America or South America yield very different results. Compared with the Port Kennedy, Conard Fissure or the California cave faunas, or those described by Lund and Winge from Brazil, the contrast is very striking. Spring faunas may be less varied, but whatever else is absent the larger ungulates are sure to be found in such situations.

The whole Antillean mammal fauna consists of only six types or groups of sub-family rank at most, as follows:

1. Ground sloths allied to *Megalonyx*—5 genera.
2. Rodents of the *Capromys* group—4 genera.



3. Rodents of the *Boromys* group—2-4 genera.
4. Rodents of the *Amblyrhiza* group—3 genera.
5. *Nesophontes* }
6. *Solenodon* } two very aberrant and primitive insectivores.

These six groups constitute the surely native fauna. Most of them are extinct; all of them except *Solenodon* are found as fossils. Sixteen genera and about thirty-five species.

There are various other mammals recorded as from one or another West Indian island. Some of them are known to have been introduced by man, others may have been. They are all species identical or closely related with continental species. If any of these were not introduced by man, they must have reached the islands in comparatively recent times, geologically speaking, not earlier than the Pleistocene, and some quite surely post-Columbian. Some are found fossil, indeed, but never much altered by petrification, in the uppermost levels of the cave and spring deposits. Such animals as the European rats, domestic cat, domestic pig, etc., belong obviously to post-Columbian time; the agoutis and armadillos of the Windward Islands and other continental American species are probably introduced by man, but they may not all be post-Columbian. Such species as the Bahaman and Martinique raccoon, the Jamaica rice rat, etc., described as distinct species, but certainly very closely related to continental species, may also have been brought by man, but long enough ago to have developed distinct races which have been accorded the rank of species. Some may indeed have come by natural means, and if so they can only have come through overseas drift, but for the present it is best to limit the discussion to the purely native groups, all of which are genera, subfamilies or families peculiar to the islands.

*The first group*, the ground sloths, consists of four very distinct genera allied to the Pliocene and Pleistocene North American *Megalonyx* and descended from the South American Miocene *Eucholops*. No Megalonychidæ are found in the South American Pliocene or Pleistocene; they are replaced by more progressive and specialized families. From the evidence one may infer that they reached the Antilles at the end of the Miocene or beginning of the Pliocene, and that the four genera specialized there in adaptation

to the insular conditions. Their peculiar specializations and the absence of any of the later and more progressive types of ground sloths that spread all over the North American continent involves isolation since that time, from North, South or Central America.

*The second group*, the rodents of the *Capromys* type, affords some contrast in its scope and relations. Instead of having four or five very divergent genera quite wide apart structurally, we have in the western Antilles, two closely allied genera, much closer in the skeleton than they are superficially. They are the only native mammals on the islands that are not on the verge of extinction; under natural conditions they would apparently be a very prosperous group. The cave records indicate they were rapidly progressing in size and increasing in relative numbers in the Pleistocene. And finally *Procapromys* of Venezuela, their nearest continental relative, is quite closely related. They have not had time to diverge very far from it in structure, although the record shows that they were diverging. The surface inference is that this group was a comparatively late arrival, perhaps early Pleistocene, perhaps late Pliocene, clearly much later than the ground sloths. Yet they had reached several of the western islands—Jamaica, Cuba, one of the Bahamas, even Little Swan Island, a small islet off the coast of Honduras. In Cuba several species of *Capromys* now exist. *Geocapromys* was formerly the principal or only type in Cuba, but is now found only in Jamaica, Little Swan Island and Plana Key on the Bahamas. In the eastern islands we find two genera less closely related. *Isolobodon* of Porto Rico is extinct and *Plagiodontia* of Hayti is practically extinct; these two are less closely related to the two western genera, but are regarded by Mr. Anthony as the eastern representatives of the group. Systematic exploration in the caves of Hayti would probably clear up the true relationship of these eastern genera; casual sketchy exploration or work undertaken simply to get material and describe new species, is very likely to destroy such evidence as exists on their palæontologic history.

*The third group*, the *Boromys* group of rodents, is extinct (possibly a single survivor) and includes a number of species belonging to two very closely related genera, doubtfully separable, one found at several points in Cuba, the other from Hayti. It is rather dis-



tantly related to the spiny rats of South America (*Echinomys*). *Heteropsomys* of Porto Rico is rather doubtfully related to this group; certainly the affinities are distant. Jamaica is unknown palæontologically.

The fourth group, the rodents of the *Amblyrhiza* group, is limited to Porto Rico and Anguilla, that is to say, to the eastern end of the east-west chain, and is wholly extinct. *Amblyrhiza*, the largest, is quite gigantic for a rodent, about the size of the Capybara or of the extinct *Castoroides*. *Elasmodontomys* of Porto Rico is nearly the size of a beaver. *Heptaxodon* of Porto Rico is a smaller form. These West Indian chinchillids are only distantly related to the living Chinchillidæ of South America, but they are quite nearly related to the *Megamys* group of the South American Pliocene.

The fifth and sixth groups of mammals, the two insectivora, are the most isolated of all the West Indian mammals, each having a family to itself. They are not at all related to each other, and their nearest relatives appear to be certain imperfectly known Eocene and Lower Oligocene genera of North America. There are no autochthonous insectivores at all in South America, save for the curious little *Necrolestes* of the Miocene, which may have had something to do with the Chrysochloridæ, but certainly not with these West Indian genera. On the other hand, insectivora occur in all the Tertiary formations of North America, and were more abundant and varied in the older Tertiaries. *Micropternodus*, of the Lower Oligocene, may have been a distant ancestor of *Solenodon*, and several of the Eocene soricoid genera from the Bridger show much resemblance to *Nesophontes*. But any exact relationship is to be regarded as provisional, and by no means proven.

Turning now to the reptiles, we find that the entire order of chelonia is represented to-day by a single species of terrapin widely distributed through the islands, found fossil in Cuba, possibly also in the island Sombrero, and closely related to the yellow-bellied terrapin of the United States. It belongs to a North American group, its nearest fossil relatives are in the southeastern states, and the few terrapins of Central and South America, which are probably rather late immigrants from North America, are less closely

related to the West Indian species. All this points strongly to Florida as the source, and the Pleistocene as the time of arrival.

A giant tortoise, new extinct, is found in Cuba. Unlike the terrapin, it is only distantly related to any other tortoises, somewhat nearer to the species of the Galapagos islands than any other. It does not appear to be especially related to any North American tortoises, except that it may be descended from some primitive species of the Miocene. True tortoises are found in the Pliocene and Pleistocene of South America, but are believed to be immigrants from the north. The Galapagos islands affinities suggest that this species may be derived from the unknown Tertiary fauna of Central America. But the Cuban species must have been isolated a long time, at least since the beginning of the Pliocene, one would judge from its peculiar specialization.

The crocodiles of the West Indies are two, one, *C. rhombifer*, peculiar to Cuba. The fossil species in Cuba is *C. rhombifer*, a broad-headed alligator-like form. It is said to be nearly related to the alleged *C. moreletii* of Central America. The other species, *C. americanus*, is found in Florida, Mexico, Central America and the west coast of South America as far as Ecuador, and appears to be rather widely distributed in the West Indies. It is probably significant that this widely distributed species inhabits the salt marshes, whereas the more local *C. rhombifer* occurs in fresh water.

The smaller reptiles and amphibians, fresh water fish, and the various groups of invertebrates are much more widely distributed throughout the West Indies. Their distribution and its causes have been extensively discussed by various authors, but unfortunately without giving due weight to two features in which it differs from the mammals and the two groups of large reptiles.

First that the dispersal of these lower groups on oceanic islands is probably chiefly brought about by storms. The eggs, attached to small debris, or even the adult animals, if small enough, will often be picked up by violent storms, and carried for considerable distances. A cyclonic storm or tornado will sometimes partly empty a shallow pond, carrying the materials a mile or more into the air, the lighter and smaller debris being carried along for a great many miles before it comes to the ground again. On account again of



their small size they would not be crushed by the fall. The distribution of the infra-mammalian groups in the West Indies, as on all other oceanic islands, appears to me to be much more in accord with this method of transportation than with any continental bridge theories or current borne drift. Mammals, however, could hardly be successfully colonized in this way, nor would it serve for chelonians or alligators. But it does probably apply to most birds and nearly all bats.

The second feature in regard to the infra-mammalian groups is that we know little or nothing of their past distribution. From such slight direct evidence as we have, and from the analogies of past distribution of the mammals, we can be reasonably sure that it was not the same in the later Tertiary as it is now, and on the same evidence I am confident that the methods of inferring past from present distribution generally used by zoögeographers are erroneous. If applied to mammals such methods would lead to conclusions absurdly in conflict with the known facts; they are in conflict with the few available data among the lower land animals; and they appear to me to be based upon erroneous theoretical reasoning.

Summarizing the data briefly we have among the mammals:

1. The ground sloths, probably of South American origin (but possibly via Central America) which must have arrived about the late Miocene or early Pliocene, and demand isolation since that date to account for their diversity, archaic type, and absence of later developed and more progressive relatives.

2. The rodents, all Hystricomorphs broadly of South American affinities, but including three groups.

- (a) Chinchillids, limited to the eastern islands, and most diverse and peculiar. They also have come from South America, but from the eastward, in the late Miocene or Pliocene.

- (b) Hutias, including an eastern and a western group (but the division line is not the same as with the chinchillids), the western group with one near relative in Venezuela, the eastern genera (Hayti and Porto Rico) more isolated. I have formulated several different hypotheses to account for the distribution, but none can be sufficiently tested by facts to be of much account. The clue lies, I think, in a knowledge of the Pliocene and Pleistocene fauna of Cen-

tral America, but the eastern representatives may have come from South America independently at an earlier date. Too few data to go upon. (See addendum, p. 181.)

(c) The *Boromys* group, known as yet very imperfectly, apparently limited to Cuba and Hayti. These also are quite distant from any continental forms, suggesting their having been isolated since the Pliocene, but so far as we know this is not supported by diversity of genera or insular specializations as among the ground sloths. The relationship to this group of the Porto Rican *Heteropsomys* is in dispute, and it is well to defer conclusions.

3. The insectivora are much more isolated than any of the preceding, but their relations are, although remotely, North American. It is with the early Tertiary fauna of North America that their apparent affinities lie.

4. The giant tortoise has distant relations with the species of the Galapagos islands, but has evidently been isolated and insular for a long time, since the Miocene or early Pliocene, but not earlier than that. The terrapin, on the other hand, is quite closely related to a living species of the southeastern states and to a group of Pleistocene species in the same region. It can hardly be supposed to be older on the islands than the Pleistocene, especially since the several islands in which it is found have not developed even distinct subspecies, although there is a good deal of individual variation.

5. The Cuban crocodile is common in the Pleistocene and probably reached the island somewhat earlier; it is nearly related to a Central American species, but it is quite as likely as not that that species was more widespread in the Pliocene, perhaps through the Southern States. (See addendum, p. 181.)

6. Birds, bats, lizards, snakes, amphibians and fresh water fishes, molluscs, insects and various other groups of invertebrates are more widespread on the islands, as they are generally on oceanic islands. I do not think the reason is so much their greater geologic age as it is their greater facilities for dispersal, especially through storms, as I have indicated. Generally speaking there are in each group forms allied closely to modern mainland forms and others which are more isolated, primitive and archaic in type, usually more



sedentary in habit or otherwise unfavorably situated for dispersal. Time is lacking to discuss these further.

Two questions are involved in the interpretation of this fauna. First as to former connections between the islands themselves, second as to former connections with the mainland.

There is considerable to be said in favor of Pleistocene or late Pliocene connections between the greater Antilles, extending as far east as the Anguilla group. In favor of this are the presence of representative species or genera of mammals as follows:

*Nesophontes* on Cuba and Porto Rico.

*Solenodon* on Cuba and Hayti.

*Miocnus* on Cuba and the closely allied *Acratocnus* on Porto Rico.

*Boromys* and *Brotomys* on Cuba and Hayti.

*Capromys* and *Geocapromys* on Cuba, Jamaica and one island of the Bahamas, also on Little Swan Island.

*Isolobodon* and *Plagiodontia* on Porto Rico and Hayti.

*Amblyrhiza* on Anguilla and *Elasmodontomys* on Porto Rico.

Against such connections are to be cited

(1) The absence of three out of the four ground sloth types from Porto Rico.

(2) Limitation of the *Capromys* group proper to the western islands, of the chinchillids to the eastern islands.

(3) Representative or replacing types are in some cases closely, in others much more distantly related as between the various islands of the chain. No specific sequence of geographic separation can be formulated that will fit the known facts. In some cases it would call for an earlier separation between Cuba and Hayti, in others between Hayti and Porto Rico.

On the whole I feel that this question is better left open till we get more data, especially as to the fossil faunas of Hayti and Jamaica.

As to the second question, of continental connections, it seems to me that the weight of evidence is very heavily against it. There are two broad considerations affecting the matter. First, the geologic evidence and the submarine topography, while they do not forbid certain former connections, are on the whole unfavorable to

any. The islands are not the remnants of a former Antillean continent; on the contrary they have been built up, partly by uplifting and uptilting of blocks along fault-lines, partly through volcanic eruptions, largely submarine, along the lines of weakness and faulting. They are not very old geologically, the oldest known rock being the marine Jurassic of western Cuba; nearly all if not all of the metamorphic rocks mapped by the U. S. Geological Survey as Palæozoic are either certainly or probably Cretaceous; and the lesser Antilles are the youngest geologically. A land connection with Florida is practically forbidden by the geology; a land connection via the lesser Antilles is unlikely in the later Tertiary, and very unlikely earlier; a land connection via Hayti, Jamaica and Honduras is unobjectionable, but there is no particular evidence in the geology or submarine topography to show that there *was* such a connection in the Tertiary. There is, however, considerable to indicate that the relatively shallow banks that stretch eastward from Honduras and Nicaragua almost to Jamaica may have been partly or wholly out of water about the Pliocene or Pleistocene. In short, if a continental connection is required by the faunal evidence, this is by all odds the most likely place for it.

The *second* general consideration is the incomplete character of the fauna. It is not a continental fauna, either North or South American, but an insular fauna arisen from development in isolation of a few individual elements of each. Such a fauna is not the result of invasion from North or from South America over a continuous land area. Its incompleteness can no longer be ascribed to extermination by man, for we see that the Pleistocene fauna, while much more extensive, was obviously and significantly incomplete and insular in type. It cannot be ascribed to scanty fossil material, for we have now very large collections of both cave and spring fossils. It cannot be ascribed to drowning out of the fauna, for we have surviving on the islands two types of Insectivora that date back to the middle or early Tertiary.

A more particular examination of the different groups of mammals, etc., confirms this general conclusion. The several groups indicate derivation from different sources geographically, and at different times geologically. If we insist upon the need of conti-



nental bridges to account for the West Indian mammals, it is not one but several bridges that they would indicate, each lasting only long enough to permit the passage of one or two of the least migratory elements of the continental faunas, and the later ones so arranged as not to disturb the isolation of the types which had already reached the islands. If continental connections be demanded, the chinchillids call for a Pliocene bridge via the lesser Antilles, not extending west of Porto Rico. The *Capromys* group calls for a Central American bridge in the late Pliocene or Pleistocene, while the ground sloths would demand a Central American bridge in the late Miocene or early Pliocene and subsequent isolation. The giant tortoises similarly would call for connection with the Galapagos islands and isolation since Miocene or early Pliocene, while the terrapin demands a Pleistocene bridge with Florida impassable for everything but one terrapin. The two insectivora similarly would call for an Oligocene connection with North America and subsequent isolation. Such conclusions seem to me inconsistent and improbable.

I do not think that one should trust blindly in these indications of former geographic relations from faunal affinities. But I do think that so far as they are of value, they should be fully and fairly presented. It will not do to pick certain points that may fit in with a particular theory, and gloss over or ignore discrepancies; nor do I see much profit in inventing elaborate hypotheses depending upon a series of unknown factors or unprovable assumptions to account for discrepancies. One may of course say that we do not know what the Tertiary fauna of Central America was like, and that it may have contained just the necessary elements to account for the West Indian fauna through a Pliocene connection. But that merely transfers the difficulties that confront one in attempting to work out any solution that conforms with all the faunal indications. It shifts the problem from the West Indies to Central America. It does not solve it.

The only explanation that seems to me conformant with all the data, physiographic, geologic and faunal, is that the islands have been populated by colonization through storms and ocean drift without land connection with the continents, but aided by extension of

the land areas to or near the borders of the continental shelf in the Pliocene and Pleistocene, and perhaps by some further connections between the greater Antilles. The mammals and chelonians would seem to be practically limited to ocean drift as a method of transportation. I have elsewhere discussed the probabilities of this method in its relation to the length of geologic time; and may add here only that if the estimates made by Barrell of the length of geologic periods are accepted, the chances become from twenty to one hundred times more favorable. For birds and bats, the smaller egg-laying vertebrates, invertebrates and plants, the agency of storms appears to afford the simplest explanation, although wave-borne drift has also doubtless played a part.

#### ADDENDUM.

Dr. Barbour's admirable memoir on the Herpetology of Cuba was published too late to incorporate in the foregoing discussion the very satisfactory solution which he supplies of the alleged Central American species *Crocodylus moreletii*. He shows that this is an error of record, the species being based upon a specimen of *C. rhombifer* from Cuba. The Cuban species is therefore an isolated one in the genus, with no near continental relatives. A study of the series of fossil skulls from Ciego Montero has been undertaken by Dr. C. C. Mook, and will be published later.

Mr. Anthony has suggested in conversation with the writer that the Venezuelan "*Procapromys*" may like *Crocodylus moreletii* be an error of record, based upon a specimen erroneously credited to Venezuela, but actually coming from one of the West Indian islands and identical with *Geocapromys* or *Capromys*. This, if verified, would clear up the affinities of the *Capromys* group conformably with the distributional relations of the other rodents, solving a very perplexing problem.



## THE RELATIVE CONTRIBUTION OF THE STAPLE COMMODITIES TO THE NATIONAL FOOD CONSUMPTION.<sup>1</sup>

By RAYMOND PEARL.

(Read April 24, 1919.)

The purpose of this paper is to present a part of the more important results of a detailed and comprehensive investigation of the food resources and utilization of the United States. The complete study will appear presently in another form, and then the supporting data on which the results here presented are based will be available. Only the final results as to *consumption of human food* will be given in the present communication.

It is quite impossible to present here any account of the critical precautions used to ensure accuracy, nor can the details of how the final results on consumption were arrived at be given in this brief paper. It is hoped that the indulgence of the reader will be granted until the appearance of the complete publication,<sup>2</sup> where all the details are set forth.

### I. THE PLAN.

The basis of any adequate survey of food resources must be essentially physiological, rather than one of commodities or trade. Broadly speaking the ultimate sources of food are the soil and the sun. The energy derived from the sun through the mechanism of the green plant builds up the inorganic chemical elements of the soil, air, and water into compounds which can be utilized as food by man, either directly or secondarily in the form of the products of animals which have been nourished on the primary foods of the plant world.

For the purpose of statistical analysis all nutritive materials pro-

<sup>1</sup> Papers from the Department of Biometry and Vital Statistics, School of Hygiene and Public Health, Johns Hopkins University, No. 4.

<sup>2</sup> Pearl, R., "The Nation's Food." In process of publication by the W. B. Saunders Co., Philadelphia.

duced and consumed fall into one or another of the following categories, which are obviously based on the considerations set forth in the preceding paragraph.

I. *Primary Foods.* Including all plant materials used as human food or fractions of such materials, and all animals or animal products in which the animal gets its nourishment from some source other than the primary feeds and fodders as defined below, either

- (a) Directly as harvested, with only such sophistication as comes from cooking, such as, for example, potatoes, fish, oysters.
- (b) In derivative form, where by process of manufacture a food product is prepared from a raw plant product; such as, for example, wheat flour or cottonseed oil.

II. *Primary Feeds or Fodders.* Including all plant materials or fractions of such materials used for the nourishment of domestic animals, either

- (a) Directly as harvested, such as the coarse grains, or
- (b) In derivative or manufactured form, such as manufactured feeds.

III. *Secondary Foods.* Including all edible products of animals used for human food nourished with primary feeds and fodders, including both produced,

- (a) Directly, without involving the death of the producing animal, such as, for example, honey, eggs, or milk, and
- (b) Derivatively, involving the death of the animal, such as, for example, the meats.

The basic idea in this classification is, of course, to allocate the nutrient resources of the nation according to the usage made of them. We have certain products of the soil, and of the seas and fresh water lakes and streams, which are directly produced and directly consumed as human food. To produce a crop of potatoes or of cod fish or oysters it is not necessary to feed out to the growing crop some other crop such as hay or grain. Therefore these are direct, primary food products. On the other hand there are many foods such as the meats, eggs, etc., where to obtain a pound of protein, or fat, or carbohydrate for human consumption it is necessary



to use a certain amount of other protein, fat, and carbohydrate primarily produced as fodder or feed. Human food produced in this manner is obviously secondarily produced and cannot be allowed to count in the net nutritive balance sheet on the same basis as the primarily produced food. It is a relatively more expensive form of nourishment.

It is evident that under this classification many raw food materials will of necessity fall in part into two or more categories. For example, to take the case of wheat, the major part of the raw grain is ground into flour and as such used as human food, but in the process of making the flour there is produced a certain amount of feeding stuffs, bran, middlings, etc., which only indirectly contribute to human nutrition through the products of animals which eat these wheat feeds. Finally a certain small proportion of the wheat grain is fed directly as such to livestock. Similar considerations apply to very many other food materials. That all this adds a considerable complexity to the problem is evident. But it is equally clear that if anything approaching reliability in the final result is to be attained, due regard must be paid to these complicated subdivisions in usage of the raw food materials. Otherwise the same nutritive material will be duplicated in the accounting and a misleading result reached.

The general plan of this study has been first to determine as accurately as possible from existing official statistics for each year from 1911-12 to 1917-18, inclusive, the amount of the basic nutrients, protein, fat and carbohydrate: (a) produced, (b) imported, (c) exported, classifying the results under the main headings given above. From this tabulation as a base one may then proceed to calculations of consumption.

In all cases where investigation showed it to be necessary deductions were made for the following kinds of reasons:

- (a) Loss of commodity in storage.
- (b) Spoilage of commodity in storage.
- (c) Loss of commodity in transit.
- (d) Spoilage of commodity in transit.
- (e) Loss by vermin.
- (f) Amount fed to livestock.
- (g) Amount used for technical, non-food purposes, including the manufacture of alcoholic beverages.

(h) Inedible refuse.

The effort was made, in the most careful and critical manner possible, to have the final figures for human food consumption represent *net* values. It is believed that this desideratum has been substantially attained. In the complete report of the study detailed statements regarding the steps taken to get net values will be given.

In making up the basic tables each commodity or derivative of a commodity was listed separately and converted as such into nutrient values. In the matter of units of measure the following general plan was followed: In all basic tables the quantities of production, export and import are first given in the American units (bushels, pounds, gallons, etc.) of the original statistics. These quantities were then all converted into metric tons.<sup>3</sup> All nutrient values, protein, fat, and carbohydrate are given in metric tons. Energy values are expressed in millions of small calories.<sup>4</sup>

Regarding the sources of the basic statistics the following general statement may be made here.<sup>5</sup> For *production* figures the fundamental sources, in the case of primary products, are the successive *Year Books* of the U. S. Department of Agriculture. Each volume of this publication carries as an appendix statistical tables giving the Department's official figures of crop production. A secondary source for crop production figures is found in the successive volumes of the *Monthly Crop Report* of the U. S. Department of Agriculture. Its figures are again official and form the basis of the tabulation of the *Year Book*, but frequently give more detailed information. Reliable statistics of the derivative products such as flour, meals, etc., are much more difficult to obtain than crop production figures, for the reason that they are not officially collected and published. In this field resort has been had to a variety of sources, such as trade papers, census returns, special *ad hoc* inquiries of manufacturers, etc.

*Export and import* figures were taken from the official reports (annual and monthly) of the foreign commerce of the United

<sup>3</sup> The metric ton = 2204.6 lbs.

<sup>4</sup> A small calory is the amount of heat necessary to raise 1 gram of water 1° Centigrade.

<sup>5</sup> This statement is supplemented by more detailed source references in the complete report of the work.



States compiled by the Department of Commerce. In a few cases where it has been clear from information available to the Food Administration that the official figures of the Department of Commerce were in error we have not hesitated to use other and, we believe, more correct statistics, but in each such case specific notation of the fact is made in the detailed report.

In the computation of nutrient values use has been made chiefly of the factors given by Atwater and Bryant.<sup>6</sup> It has been necessary, in some cases, to supplement their tables from data given by Leach<sup>7</sup> and Henry and Morrison.<sup>8</sup>

All calculations in this work have been repeatedly checked and every possible precaution taken to guard against error. It is too much to hope that so extensive a piece of statistical work should be without errors, but I hope that their number is small and their net significance in the final results negligible.

## II. THE CONSUMPTION OF HUMAN FOOD IN THE UNITED STATES.

Hitherto there have been available only the roughest guesses as to the total domestic consumption of all but a few items of food, such as wheat and sugar. If anyone were confronted with the naïve and simple question, "How much corn, or oats, or molasses, or fish, or milk, or nuts," or any one of a long series of other foods, "is consumed annually in the United States as human food," no accurate answer could be given. Yet the question is obviously a fair one, and one which somebody in the nation ought to be able to answer with a considerable degree of accuracy. For some twenty-odd great staple commodities or groups of like commodities we are now in a position to present figures of a relatively high degree of accuracy as to consumption. On the basis of these figures it is possible to discuss effectively many interesting and important problems; such as, for example, that of the relative importance of great

<sup>6</sup> Atwater, W. O., and Bryant, A. P., "The Chemical Composition of American Food Materials" (Corrected April 14, 1906), U. S. Dept. Agr. Office of Expt. Sta. Bulletin 28 (revised edition), 1906.

<sup>7</sup> Leach, A. E., "Food Inspection and Analysis." Third edition, revised and enlarged by A. L. Winton, New York, 1913.

<sup>8</sup> Henry, W. A., and Morrison, F. B., "Feeds and Feeding." Sixteenth edition. Madison, 1916.

TABLE I.  
THE CONSUMPTION OF HUMAN FOODS IN THE UNITED STATES, 1911 TO 1918  
(METRIC TONS).

Commodity.	1911-12.				1912-13.			
	Protein in Metric Tons.	Fat in Metric Tons.	Carbohydrate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carbohydrate in Metric Tons.	Calories in Millions.
<i>Grains and Derivative Products</i>								
Wheat and products.....	1,000,730	87,132	6,586,209	31,033,764	995,249	86,726	6,553,141	31,750,774
Corn products.....	205,809	99,007	1,831,949	9,283,484	203,748	98,245	1,814,153	9,189,386
Rye products.....	10,215	1,351	118,242	539,899	10,201	1,416	123,843	595,476
Rice and products.....	13,472	338	133,036	605,503	15,840	397	156,420	711,928
Other cereals.....	26,728	10,457	150,341	824,114	26,114	10,293	145,068	798,429
<i>Sub-total—Grains.....</i>	<i>1,256,954</i>	<i>198,885</i>	<i>8,822,777</i>	<i>43,186,764</i>	<i>1,251,652</i>	<i>197,077</i>	<i>8,792,625</i>	<i>43,024,993</i>
<i>Vegetables</i>								
Legumes.....	66,717	4,619	174,915	1,034,622	70,279	4,830	184,215	1,089,145
Potatoes.....	100,861	5,604	823,688	3,843,272	130,412	7,578	1,114,025	5,197,962
Other vegetables.....	28,662	9,607	282,235	1,367,003	29,537	9,682	285,777	1,385,885
<i>Sub-total—Vegetables.....</i>	<i>196,240</i>	<i>19,830</i>	<i>1,280,838</i>	<i>6,244,897</i>	<i>230,228</i>	<i>22,090</i>	<i>1,584,017</i>	<i>7,672,992</i>
<i>Sugars.....</i>	<i>454</i>	<i>0</i>	<i>3,906,511</i>	<i>16,021,424</i>	<i>455</i>	<i>0</i>	<i>4,104,958</i>	<i>16,835,176</i>
<i>Fruits</i>								
Apples.....	8,646	8,500	309,136	1,388,209	9,519	9,406	341,068	1,531,633
Oranges.....	1,571	392	30,223	132,308	1,589	397	30,558	133,866
Bananas.....	7,575	3,788	121,214	593,684	7,219	3,600	115,509	537,156
Other fruits.....	6,492	7,173	151,684	710,188	8,171	7,288	184,418	851,392
<i>Sub-total—Fruits.....</i>	<i>24,284</i>	<i>19,853</i>	<i>612,257</i>	<i>2,794,479</i>	<i>26,498</i>	<i>20,700</i>	<i>671,553</i>	<i>3,054,047</i>



TABLE I.—(Continued.)  
THE CONSUMPTION OF HUMAN FOODS IN THE UNITED STATES, 1911 TO 1918  
(METRIC TONS).

Commodity.	1911-12.				1912-13.			
	Protein in Metric Tons.	Fat in Metric Tons.	Carbohy- drate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carbohy- drate in Metric Tons.	Calories in Millions.
<i>Vegetable Oils and Nuts</i>								
Nuts.....	40,460	77,555	30,491	1,012,435	43,369	81,228	32,932	1,068,492
Vegetable oils.....	0	464,403	0	4,321,053	0	458,136	0	4,262,661
Chocolate and cocoa.....	8,312	19,470	16,242	280,323	7,078	18,676	15,593	268,987
<i>Sub-total—Oils and Nuts.....</i>	<i>48,772</i>	<i>561,428</i>	<i>46,733</i>	<i>5,613,821</i>	<i>51,347</i>	<i>558,040</i>	<i>48,525</i>	<i>5,600,140</i>
<i>Fish.....</i>	<i>86,948</i>	<i>19,176</i>	<i>20</i>	<i>552,810</i>	<i>85,016</i>	<i>18,477</i>	<i>20</i>	<i>538,436</i>
<i>Sub-total—All primary.....</i>	<i>1,613,652</i>	<i>819,172</i>	<i>14,669,136</i>	<i>74,414,195</i>	<i>1,651,196</i>	<i>816,384</i>	<i>15,201,698</i>	<i>76,725,784</i>
<i>Meats and Meat Products</i>								
Beef and products.....	546,104	516,545	1,725	7,072,130	521,798	496,430	1,649	6,784,205
Pork and products.....	388,745	1,963,696	2,664	19,874,512	381,901	1,926,270	2,597	19,498,083
Mutton and products.....	45,782	61,405	521	762,158	48,677	70,612	542	859,246
<i>Sub-total—Meats.....</i>	<i>979,631</i>	<i>2,541,621</i>	<i>4,801</i>	<i>27,705,272</i>	<i>951,570</i>	<i>2,494,770</i>	<i>4,766</i>	<i>27,151,638</i>
<i>Poultry and Eggs.....</i>	<i>235,699</i>	<i>165,966</i>	<i>0</i>	<i>2,508,307</i>	<i>239,584</i>	<i>168,659</i>	<i>0</i>	<i>2,549,776</i>
<i>Oleomargarine.....</i>	<i>680</i>	<i>47,038</i>	<i>0</i>	<i>449,412</i>	<i>774</i>	<i>53,539</i>	<i>0</i>	<i>501,291</i>
<i>Dairy Products.....</i>	<i>726,604</i>	<i>1,368,995</i>	<i>880,525</i>	<i>19,337,072</i>	<i>720,632</i>	<i>1,358,126</i>	<i>872,694</i>	<i>19,179,262</i>
<i>Sub-total—All secondary.....</i>	<i>1,942,064</i>	<i>4,123,560</i>	<i>885,416</i>	<i>49,991,663</i>	<i>1,912,560</i>	<i>4,075,094</i>	<i>877,460</i>	<i>49,381,967</i>
<i>Grand Total.....</i>	<i>3,556,616</i>	<i>4,942,732</i>	<i>15,554,552</i>	<i>124,405,258</i>	<i>3,563,756</i>	<i>4,891,478</i>	<i>16,079,158</i>	<i>126,107,751</i>

TABLE I.—(Continued.)  
THE CONSUMPTION OF HUMAN FOODS IN THE UNITED STATES, 1911 TO 1918  
(METRIC TONS).

Commodity.	1913-14.				1914-15.			
	Protein in Metric Tons.	Fat in Metric Tons.	Carbohy- drate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carbohy- drate in Metric Tons.	Calories in Millions.
<i>Grains and Derivative Products</i>								
Wheat and products.....	1,166,243	101,745	7,679,947	37,217,595	978,866	85,316	6,446,223	31,240,761
Corn products.....	202,368	97,263	1,802,353	9,126,239	201,593	96,571	1,795,051	9,086,301
Rye products.....	11,123	1,479	120,304	590,413	11,228	1,486	129,936	593,297
Rice and products.....	18,636	465	184,022	837,569	13,427	337	132,597	603,495
Other cereals.....	29,981	12,119	158,441	885,682	28,572	11,601	149,850	840,316
<i>Sub-total—Grains.....</i>	<i>1,428,401</i>	<i>213,071</i>	<i>9,953,107</i>	<i>48,657,498</i>	<i>1,233,536</i>	<i>195,311</i>	<i>8,653,657</i>	<i>42,364,164</i>
<i>Vegetables</i>								
Legumes.....	76,757	5,282	202,149	1,193,370	68,833	4,869	179,423	1,063,900
Potatoes.....	108,850	6,046	888,931	4,147,685	132,339	7,353	1,080,780	5,042,836
Other vegetables.....	28,605	9,178	286,216	1,379,545	33,441	10,126	304,875	1,484,686
<i>Sub-total—Vegetables.....</i>	<i>214,212</i>	<i>20,506</i>	<i>1,377,296</i>	<i>6,720,600</i>	<i>234,613</i>	<i>22,348</i>	<i>1,565,018</i>	<i>7,591,416</i>
<i>Sugars.....</i>	<i>455</i>	<i>0</i>	<i>4,423,200</i>	<i>18,140,160</i>	<i>455</i>	<i>0</i>	<i>4,319,726</i>	<i>17,715,852</i>
<i>Fruits</i>								
Apples.....	5,792	5,791	207,210	930,502	10,256	10,141	367,567	1,650,637
Oranges.....	1,526	381	29,358	128,607	1,499	374	28,839	126,340
Bananas.....	8,222	4,111	131,567	611,836	6,914	3,447	110,304	512,951
Other fruits.....	6,656	7,668	150,045	768,077	7,878	6,607	169,753	783,643
<i>Sub-total—Fruits.....</i>	<i>22,196</i>	<i>17,801</i>	<i>518,180</i>	<i>2,379,022</i>	<i>26,547</i>	<i>20,569</i>	<i>676,463</i>	<i>3,073,571</i>



TABLE I.—(Continued.)  
THE CONSUMPTION OF HUMAN FOODS IN THE UNITED STATES, 1911 TO 1918  
(METRIC TONS.)

Commodity.	1913-14.					1914-15.				
	Protein in Metric Tons.	Fat in Metric Tons.	Carboly- hydrate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carboly- hydrate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Calories in Millions.
<i>Vegetable Oils and Nuts</i>										
Nuts.....	50,244	95,092	38,381	1,247,095	50,929	95,006	38,400	1,250,900		
Vegetable oils.....	0	541,477	0	5,038,094	0	595,041	0	5,536,504		
Chocolate and cocoa.....	10,200	23,885	19,931	343,932	9,195	21,574	17,954	310,281		
<i>Sub-total—Oils and Nuts.....</i>	<i>60,444</i>	<i>660,454</i>	<i>58,312</i>	<i>6,630,021</i>	<i>60,124</i>	<i>711,711</i>	<i>56,354</i>	<i>7,097,685</i>		
<i>Fish.....</i>	<i>86,108</i>	<i>18,563</i>	<i>18</i>	<i>543,899</i>	<i>86,796</i>	<i>18,732</i>	<i>19</i>	<i>548,479</i>		
<i>Sub-total—All primary.....</i>	<i>1,811,816</i>	<i>930,395</i>	<i>16,330,173</i>	<i>83,071,200</i>	<i>1,642,071</i>	<i>968,671</i>	<i>15,271,237</i>	<i>78,301,167</i>		
<i>Meats and Meat Products</i>										
Beef and products.....	597,758	486,631	1,583	6,634,517	598,717	490,365	1,662	6,673,341		
Pork and products.....	364,500	1,855,128	2,482	18,764,355	416,899	2,157,016	2,873	21,797,474		
Mutton and products.....	48,684	77,397	535	922,389	42,256	64,254	462	773,384		
<i>Sub-total—Meats.....</i>	<i>930,379</i>	<i>2,419,465</i>	<i>4,586</i>	<i>26,321,773</i>	<i>967,165</i>	<i>2,707,408</i>	<i>4,980</i>	<i>29,193,531</i>		
<i>Poultry and Eggs.....</i>	<i>244,065</i>	<i>172,484</i>	<i>0</i>	<i>2,607,319</i>	<i>249,006</i>	<i>175,349</i>	<i>0</i>	<i>2,650,480</i>		
<i>Oleomargarine.....</i>	<i>770</i>	<i>53,261</i>	<i>0</i>	<i>498,672</i>	<i>765</i>	<i>52,017</i>	<i>0</i>	<i>495,407</i>		
<i>Dairy Products.....</i>	<i>731,613</i>	<i>1,379,896</i>	<i>884,160</i>	<i>19,473,916</i>	<i>742,130</i>	<i>1,400,402</i>	<i>903,312</i>	<i>19,787,471</i>		
<i>Sub-total—All secondary.....</i>	<i>1,867,727</i>	<i>4,025,106</i>	<i>888,746</i>	<i>48,901,686</i>	<i>1,950,666</i>	<i>4,336,166</i>	<i>908,292</i>	<i>52,126,940</i>		
<i>Grand Total.....</i>	<i>3,709,543</i>	<i>4,955,501</i>	<i>17,218,919</i>	<i>131,972,880</i>	<i>3,601,137</i>	<i>5,304,837</i>	<i>16,179,529</i>	<i>130,518,116</i>		

TABLE I.—(Continued.)

THE CONSUMPTION OF HUMAN FOODS IN THE UNITED STATES, 1911 TO 1918  
(METRIC TONS.)

Commodity.	1915-16.				1916-17.				1917-18.			
	Protein in Metric Tons.	Fat in Metric Tons.	Carbohy- drate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carbohy- drate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carbohy- drate in Metric Tons.	Calories in Millions.
<i>Grains and Derivative Products</i>												
Wheat and products.....	1,159,286	101,146	7,636,118	37,007,387	1,026,976	89,506	6,765,024	32,784,510	940,543	81,835	6,105,182	30,021,979
Corn products.....	201,163	96,173	1,792,381	9,070,259	201,769	96,260	1,797,497	9,094,401	242,305	118,845	2,155,310	10,038,521
Rye products.....	11,480	3,519	132,856	606,633	12,245	1,621	141,725	647,129	24,597	3,256	284,668	1,299,820
Rice and products.....	16,677	417	164,991	749,578	25,331	634	250,140	1,138,508	30,725	767	303,428	1,381,039
Other cereals.....	32,131	13,292	161,941	920,265	39,298	16,587	189,036	1,091,501	65,088	23,104	352,857	1,927,904
<i>Sub-total—Grains.....</i>	<i>1,420,737</i>	<i>212,547</i>	<i>9,887,987</i>	<i>48,354,122</i>	<i>1,305,559</i>	<i>204,617</i>	<i>9,143,422</i>	<i>44,756,049</i>	<i>1,303,348</i>	<i>227,807</i>	<i>9,291,445</i>	<i>45,560,323</i>
<i>Vegetables</i>												
Legumes.....	59,707	4,145	153,757	913,944	75,821	5,200	198,157	1,172,609	105,578	7,325	277,203	1,638,716
Potatoes.....	115,422	6,412	942,229	4,398,237	93,793	5,295	765,232	3,570,508	143,167	7,953	1,169,204	5,455,418
Other vegetables.....	32,292	10,998	346,643	1,660,414	28,284	10,611	317,522	1,514,539	36,668	12,586	398,275	1,904,998
<i>Sub-total—Vegetables.....</i>	<i>207,321</i>	<i>21,555</i>	<i>1,443,029</i>	<i>6,972,595</i>	<i>197,898</i>	<i>20,426</i>	<i>1,280,911</i>	<i>6,257,656</i>	<i>285,413</i>	<i>27,864</i>	<i>1,844,682</i>	<i>8,999,132</i>
<i>Sugars.....</i>	<i>455</i>	<i>0</i>	<i>4,047,276</i>	<i>16,598,665</i>	<i>455</i>	<i>0</i>	<i>4,356,901</i>	<i>17,868,295</i>	<i>439</i>	<i>0</i>	<i>4,374,104</i>	<i>17,939,129</i>
<i>Fruits</i>												
Apples.....	9,610	9,567	345,335	1,550,836	8,490	8,461	305,219	1,370,683	7,458	7,451	268,425	1,205,454
Oranges.....	1,523	379	29,286	128,293	2,176	544	41,912	183,597	1,109	278	21,360	93,569
Bananas.....	6,169	3,085	98,717	459,065	5,778	2,889	92,457	429,900	5,771	2,885	92,360	429,360
Other fruits.....	9,295	9,174	206,025	991,649	7,227	8,429	167,517	790,038	9,283	6,767	219,237	994,221
<i>Sub-total—Fruits.....</i>	<i>26,597</i>	<i>22,205</i>	<i>679,463</i>	<i>3,099,843</i>	<i>23,671</i>	<i>20,323</i>	<i>607,105</i>	<i>2,774,278</i>	<i>23,621</i>	<i>17,381</i>	<i>601,350</i>	<i>2,722,604</i>



TABLE I.—(Concluded.)  
THE CONSUMPTION OF HUMAN FOODS IN THE UNITED STATES, 1911 TO 1918  
(METRIC TONS.)

Commodity.	1915-16.				1916-17.				1917-18.			
	Protein in Metric Tons.	Fat in Metric Tons.	Carbohydrate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carbohydrate in Metric Tons.	Calories in Millions.	Protein in Metric Tons.	Fat in Metric Tons.	Carbohydrate in Metric Tons.	Calories in Millions.
<i>Vegetable Oils and Nuts</i>												
Nuts.....	47,957	99,492	36,507	1,271,000	47,957	105,623	36,717	1,329,746	81,939	179,337	63,054	2,262,988
Vegetable oils.....	0	424,858	0	3,953,026	0	547,294	0	5,092,191	0	554,851	0	5,162,528
Chocolate and cocoa.....	11,880	27,881	23,200	400,975	18,554	43,530	36,235	626,117	20,083	47,273	39,177	678,641
<i>Sub-total—Oils and Nuts.....</i>	<i>59,837</i>	<i>552,231</i>	<i>59,707</i>	<i>5,625,001</i>	<i>66,511</i>	<i>606,447</i>	<i>72,952</i>	<i>7,048,054</i>	<i>102,022</i>	<i>781,461</i>	<i>102,231</i>	<i>8,104,157</i>
<i>Fish.....</i>	<i>79,068</i>	<i>16,045</i>	<i>20</i>	<i>495,706</i>	<i>84,475</i>	<i>17,582</i>	<i>23</i>	<i>527,725</i>	<i>85,041</i>	<i>17,866</i>	<i>25</i>	<i>533,419</i>
<i>Sub-total—All primary.....</i>	<i>1,794,915</i>	<i>824,583</i>	<i>16,117,382</i>	<i>81,146,832</i>	<i>1,678,279</i>	<i>959,395</i>	<i>15,461,314</i>	<i>79,232,057</i>	<i>1,799,864</i>	<i>1,072,379</i>	<i>16,213,937</i>	<i>83,867,764</i>
<i>Meats and Meat Products</i>												
Beef and products.....	525,129	502,065	1,740	6,850,539	562,748	538,151	1,881	7,342,374	539,703	513,596	1,577	7,017,398
Pork and products.....	495,161	2,143,483	2,959	21,614,254	398,781	2,098,923	2,895	21,173,213	378,799	2,045,653	2,859	20,594,616
Mutton and products.....	40,286	62,637	439	759,130	36,589	56,646	406	678,884	28,298	46,853	315	553,498
<i>Sub-total—Meats.....</i>	<i>969,677</i>	<i>2,706,434</i>	<i>5,076</i>	<i>29,130,535</i>	<i>996,527</i>	<i>2,685,983</i>	<i>5,146</i>	<i>29,115,663</i>	<i>945,277</i>	<i>2,602,187</i>	<i>4,717</i>	<i>28,122,722</i>
<i>Poultry and Eggs.....</i>	<i>252,314</i>	<i>177,696</i>	<i>0</i>	<i>2,685,822</i>	<i>255,499</i>	<i>179,999</i>	<i>0</i>	<i>2,720,161</i>	<i>248,772</i>	<i>175,220</i>	<i>0</i>	<i>2,648,262</i>
<i>Oleomargarine.....</i>	<i>800</i>	<i>55,375</i>	<i>0</i>	<i>518,470</i>	<i>1,238</i>	<i>85,658</i>	<i>0</i>	<i>802,095</i>	<i>1,808</i>	<i>125,024</i>	<i>0</i>	<i>1,170,593</i>
<i>Dairy Products.....</i>	<i>764,377</i>	<i>1,445,669</i>	<i>919,595</i>	<i>20,366,131</i>	<i>783,350</i>	<i>1,482,331</i>	<i>937,858</i>	<i>20,860,208</i>	<i>788,909</i>	<i>1,595,129</i>	<i>917,169</i>	<i>21,010,397</i>
<i>Sub-total—All secondary.....</i>	<i>1,986,568</i>	<i>4,379,174</i>	<i>924,671</i>	<i>52,700,958</i>	<i>2,036,614</i>	<i>4,433,971</i>	<i>943,004</i>	<i>53,498,037</i>	<i>1,984,826</i>	<i>4,407,560</i>	<i>921,886</i>	<i>52,951,974</i>
<i>Grand Total.....</i>	<i>3,781,483</i>	<i>5,203,757</i>	<i>17,042,953</i>	<i>133,853,790</i>	<i>3,714,893</i>	<i>5,393,366</i>	<i>16,404,318</i>	<i>132,730,094</i>	<i>3,784,690</i>	<i>5,479,939</i>	<i>17,135,813</i>	<i>136,819,728</i>

groups of staples, like the grains and the vegetables, in the nutrition of the people of the nation. We can calculate with accuracy the total national food bill, and so forth.

The final net results as to consumption of human foods in the United States during the seven years are set forth in Table I. In that table the results are given for the several nutrient values, protein, fat, carbohydrate and calories, only. This is the most scien-

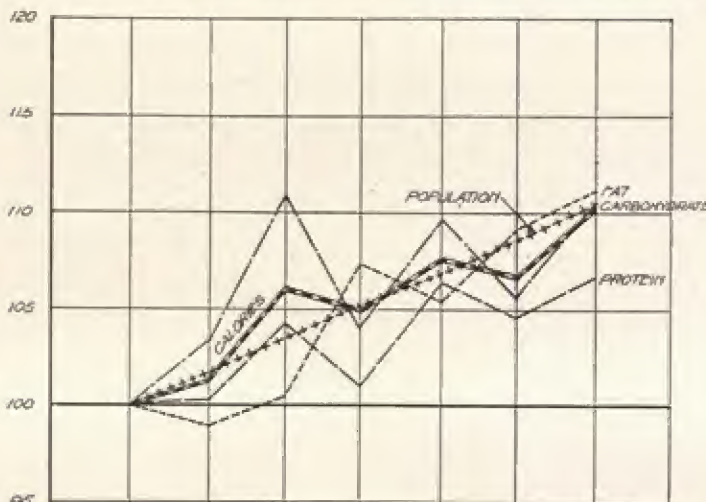


FIG. 1. Relative curves for human food consumption. The figure for the year 1911-12 is taken as 100 in each case and the relative figure for each year calculated to that base.

tific, and as soon as one become accustomed to it, by far the most useful way of thinking about food consumption.

The data of Table I. are summarized by years in Table II., and are shown graphically in relative form in Fig. 1.

The first thing which impresses one about the consumption figures is their extreme uniformity from year to year, as compared with production, exports and imports. This is exactly what would be expected, of course. No matter how much production, exports and imports may fluctuate, within wide limits, the people of this country eat about the same amount each year. To have the statistical calculation come out to this result so beautifully is strong evidence of the correctness of the long and tedious preliminary cal-



TABLE II.

SUMMARY OF CONSUMPTION OF HUMAN FOODS, PRIMARY AND SECONDARY  
(METRIC TONS).

	Protein.	Per Cent. from		Fat.	Per Cent. from		Carbohydrate.	Per Cent. from		Calories (Millions).	Per Cent. from	
		Primary.	Secondary.		Primary.	Secondary.		Primary.	Secondary.		Primary.	Secondary.
1911-12.....	3,556,616	45	55	4,942,732	17	83	15,554,552	94	6	124,495,258	60	40
1912-13.....	3,563,756	46	54	4,891,478	17	83	16,079,158	95	5	126,107,751	61	39
1913-14.....	3,709,543	49	51	4,955,501	19	81	17,218,919	95	5	131,972,880	63	37
1914-15.....	3,601,137	46	54	5,304,837	18	82	16,179,529	94	6	130,518,116	60	40
1915-16.....	3,781,483	47	53	5,203,757	16	84	17,042,953	95	5	133,853,790	61	39
1916-17.....	3,714,893	45	55	5,393,366	18	82	16,404,318	94	6	132,730,094	60	40
1917-18.....	3,784,690	48	52	5,479,939	20	80	17,135,813	95	5	136,819,738	61	39
Total for 7 years.....	25,712,118	47	53	36,171,610	18	82	115,614,342	95	5	916,407,627	61	39
Average, whole period.....	3,673,160	47	53	5,167,373	18	82	16,516,335	95	5	130,915,375	61	39
Average, 1911-12, 1916-17.....	3,654,571	46	54	5,115,279	17	83	16,413,088	95	5	129,931,315	61	39

culations. There has been a rather steady small increase in total gross food consumption, but this has been very closely proportional to the increase in the population.

In the seven-year period here discussed the greatest relative advance in consumption was in respect of fat, and the least relative advance in respect of protein. Carbohydrate content and calories increased in the seven years in amount consumed to a degree intermediate between fat and protein. The protein relative line falls below the population relative line each year after 1913-14. This means that since 1913-14 somewhat less protein has been consumed in gross in proportion to the population. The relative line for fat was below the population line till 1914-15, and thereafter followed it closely.

The relative figures from which Fig. 1 is plotted are given in Table III.

With such gratifying assurance of the smoothness of the consumption results we may proceed to an analytical discussion of the numerous highly interesting problems which center about human food consumption, and for which data have hitherto been lacking.

TABLE III.  
CONSUMPTION OF HUMAN FOODS, PRIMARY AND SECONDARY, RELATIVE TO  
1911-12, TAKEN AS 100.

	Population.	Protein.	Fat.	Carbohy- drate.	Calories (Millions).
1911-12.....	100.0	100.0	100.0	100.0	100.0
1912-13.....	101.7	100.2	99.0	103.4	101.4
1913-14.....	103.4	104.3	100.3	110.7	106.1
1914-15.....	105.1	101.3	107.3	104.0	104.9
1915-16.....	106.8	106.3	105.3	109.6	107.6
1916-17.....	108.5	104.5	109.1	105.5	106.7
1917-18.....	110.2	106.4	110.9	110.2	110.0
Average, whole period.....	105.1	103.3	104.6	106.2	105.2
Average, 1911-12 to 1916-17...	104.3	102.8	103.5	105.5	104.5

The first of such problems to which attention may be turned is: To what relative degree do primary, as distinguished from secondary, human foods contribute to the total nutritional intake of our population? From Table II. it is seen that of the protein consumed 47 per cent. comes from primary sources and 53 per cent. from secondary sources. Thus, broadly speaking, the American people get over one half of their protein from animal sources exclusive of fish, which are included in the primary foods. This fact indicates at once the importance of maintaining our animal herds intact and keeping the price of animal products at not too high a level, unless we are prepared to face the alternative of a radical and fundamental alteration in the established dietary habits of the people.

In general there has been but little change in this protein-source dietary habit in the seven years included in this study. What change there has been is in the direction of a smaller proportion of protein from secondary sources and a larger from primary, but the movement has been but slight. As would be expected, a much larger proportion of the total fat consumed in human food comes from secondary sources than is the case with protein. The figures are 82 per cent. from secondary sources and 18 per cent. from primary. Again there has been little change in the seven years. In spite of all propaganda from dietary cranks and from commercial interests, it is clear that the American people depend to an overwhelming degree upon animal sources for their fat intake, rather



than upon vegetable oils, nuts and the like. This condition is naturally reversed as regards carbohydrate. Ninety-four per cent. of this nutrient comes from primary sources and only 5 from second-

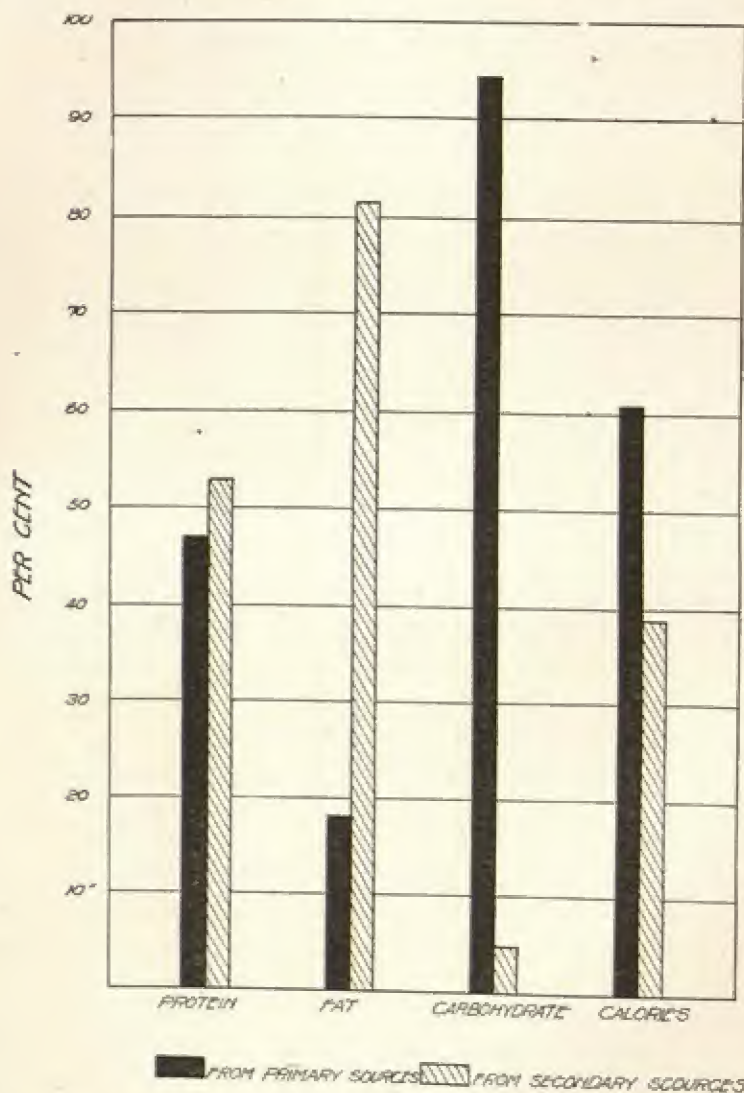


FIG. 2. Diagram showing the percentages of the total nutritional intake of the American people derived from primary and secondary sources.

ary. In the total nutritional calory intake 61 per cent. comes from primary foods and 39 per cent. from secondary.

It is interesting to compare the percentage of American nutritional intake derived from primary and secondary sources with cor-

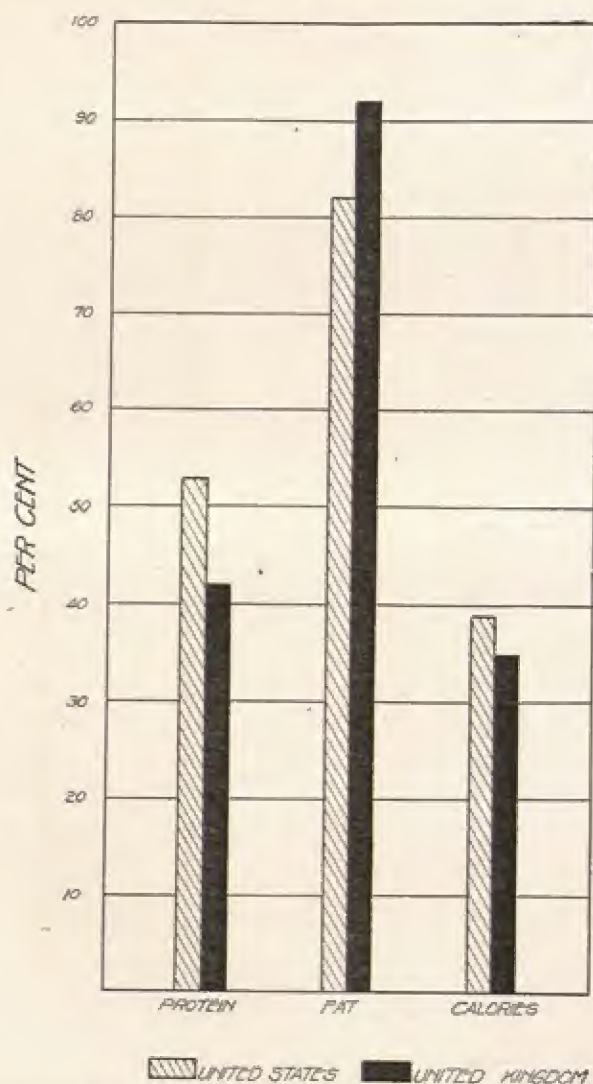


FIG. 3. Diagram showing the relative proportions of the American and British food intake derived from animal sources (exclusive of fish).



responding British figures. Calculating roughly from Table I. of the official British report<sup>9</sup> on the subject I find that 42 per cent. of the protein intake, 92 per cent. of the fat intake, and 35 per cent. of the energy value of the total nourishment of the population of the United Kingdom comes from *secondary* sources. In other words, the British get less of their protein and calories and more of their fat from animal products exclusive of fish than the Americans do. The differences, however, are not very great, indicating generally similar dietary habits in the two populations, a fact which we know on general grounds to be true.

The above comparisons regarding primary and secondary sources of human food are shown graphically in Figs. 2 and 3.

The next problem concerns the relative proportion of the total nutritional intake furnished by the several different large food commodity classes. The data on this point for the main groups are collected in Tables IV.-VII. and IX.-XII. inclusive. The arrangement of these tables is to give first the annual average for the six years preceding the entrance of the United States into the war, and then to give 1917-18, our first year in the war, separately. The reason for such a time division is obvious. There is no reason to suppose that the consumption of food in this country was affected by the war till the time we entered and the United States Food Administration began its work. Before then the population had gone on consuming food at about the usual normal rate. There was no reason or incentive to do otherwise, except in so far as price had an influence. But in 1917-18 a wholly new and extraordinary influence was brought into play to alter the national food habits. This was the Food Administration, which through its recommendations, on the one hand, and regulations on the other hand, sought to modify the consumption rate of certain commodities and succeeded in doing so, as will presently appear in detail.

In Tables IV. to VII. the percentage figures are first given separately and then accumulated to 100 in another column.

The data of Tables IV. and VII. are shown graphically in Fig. 4.

<sup>9</sup> "The Food Supply of the United Kingdom." A report drawn up by a Committee of the Royal Society at the request of the Board of Trade. London (Cd. 8421), 1917, pp. 35.

TABLE IV.

CONSUMPTION OF PROTEIN IN HUMAN FOODS, PRIMARY AND SECONDARY, IN THE UNITED STATES, ARRANGED BY GROUPS IN ORDER OF MAGNITUDE.

Group.	Average for the Six Years, 1911-12 to 1916-17.			For 1917-18.		
	Absolute Consumption of Protein (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.	Absolute Consumption of Protein (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.
Grains.....	1,316,140	36.01	36.01	1,303,348	34.44	34.44
Meats.....	964,117	26.38	62.39	945,277	24.98	59.42
Dairy products.....	744,784	20.38	82.77	788,969	20.85	80.27
Poultry and eggs....	246,178	6.74	89.51	285,413	7.54	87.81
Vegetables.....	214,404	5.87	95.38	248,772	6.57	94.38
Fish.....	84,852	2.32	97.70	102,022	2.69	97.07
Oils and nuts.....	57,839	1.58	99.28	85,021	2.25	99.32
Fruits.....	24,965	.69	99.97	23,621	.62	99.94
Oleomargarine.....	838	.02	99.99	1,808	.05	99.99
Sugars.....	455	.01	100.00	439	.01	100.00
Total.....	3,654,572	100.00	—	3,784,690	100.00	—

From these tables and diagrams it is seen that the grains stand at the head of the list in contribution of protein, carbohydrate and calories. Meats come first in contribution of fat, second in protein and calories. Thirty-six per cent. of our protein intake normally is in the form of grain, 26 per cent. in meats and 20 per cent. in

TABLE V.

CONSUMPTION OF FAT IN HUMAN FOODS, PRIMARY AND SECONDARY, IN THE UNITED STATES, ARRANGED BY GROUPS IN ORDER OF MAGNITUDE.

Group.	Average for the Six Years, 1911-12 to 1916-17.			For 1917-18.		
	Absolute Consumption of Fat (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.	Absolute Consumption of Fat (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.
Meats.....	2,591,613	50.66	50.66	2,602,187	47.48	47.48
Dairy products.....	1,405,918	27.49	78.15	1,505,129	27.46	74.94
Oils and nuts.....	623,385	12.19	90.34	781,461	14.26	89.20
Grains.....	203,585	3.98	94.32	227,807	4.16	93.36
Poultry and eggs....	173,349	3.39	97.71	175,220	3.20	96.56
Oleomargarine.....	57,965	1.13	98.84	125,024	2.28	98.84
Vegetables.....	21,126	.41	99.25	27,864	.51	99.35
Fruits.....	20,242	.49	99.65	17,866	.33	99.68
Fish.....	18,096	.35	100.00	17,381	.32	100.00
Sugars.....	0	0	100.00	0	0	100.00
Total.....	5,115,279	100.00	—	5,479,939	100.00	—



TABLE VI.

CONSUMPTION OF CARBOHYDRATES IN HUMAN FOODS, PRIMARY AND SECONDARY, IN THE UNITED STATES, ARRANGED BY GROUPS IN ORDER OF MAGNITUDE.

Group.	For the Six Years, 1911-12 to 1916-17.			For 1917-18.		
	Absolute Consumption of Carbohydrate (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.	Absolute Consumption of Carbohydrate (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.
Grains.....	9,208,939	56.1073	56.1073	9,291,445	54.2224	54.2224
Sugars.....	4,193,095	25.5473	81.6546	4,374,194	25.5266	79.7490
Vegetables.....	1,421,851	8.6629	90.3175	1,844,682	10.7651	90.5141
Dairy products.....	899,691	5.4815	95.7990	917,169	5.3524	95.8665
Fruits.....	627,487	3.8231	99.6221	601,350	3.5993	99.3758
Oils and nuts.....	57,097	.3479	99.9700	102,231	.5966	99.9724
Meats.....	4,907	.0299	99.9999	4,717	.0275	99.9999
Fish.....	20	.0001	100.0000	25	.0001	100.0000
Poultry and eggs.....	0	0	100.0000	0	0	100.0000
Oleomargarine.....	0	0	100.0000	0	0	100.0000
Total.....	16,413,087	100.0000	—	17,135,813	100.0000	—

dairy products. These three great commodity groups together make up nearly 83 per cent. of our total protein intake.

The total consumption of human food was higher in 1917-18 than the average of the preceding six years. This is to be expected from the greater prosperity of the people incident to high wages,

TABLE VII.

CONSUMPTION OF HUMAN FOODS, PRIMARY AND SECONDARY, IN THE UNITED STATES, IN TERMS OF CALORIC VALUE, ARRANGED BY GROUPS IN ORDER OF MAGNITUDE.

Group.	For the Six Years, 1911-12 to 1916-17.			For 1917-18.		
	Absolute Consumption (Million Calories).	Percentage Consumption.	Cumulated Per Cent.	Absolute Consumption (Million Calories).	Percentage Consumption.	Cumulated Per Cent.
Grains.....	45,057,265	34.68	34.68	45,569,323	33.31	33.31
Meats.....	28,104,069	21.63	56.31	28,122,722	20.55 +	53.86
Dairy products.....	19,834,010	15.26	71.57	21,010,397	15.36	69.22
Sugars.....	17,196,595	13.24	84.81	17,939,129	13.11	82.33
Vegetables.....	6,910,026	5.32	90.13	8,999,132	6.58	88.91
Oil and nuts.....	6,269,270	4.82	94.95	8,104,157	5.92	94.83
Fruits.....	2,862,540	2.20	97.15	2,722,604	1.99	96.82
Poultry and eggs.....	2,620,311	2.02	99.17	2,648,262	1.93	98.75
Oleomargarine.....	542,719	.42	99.59	1,170,593	.86 -	99.61
Fish.....	534,509	.41	100.00	533,419	.39	100.00
Total.....	129,931,314	100.00	—	136,819,738	100.00	—

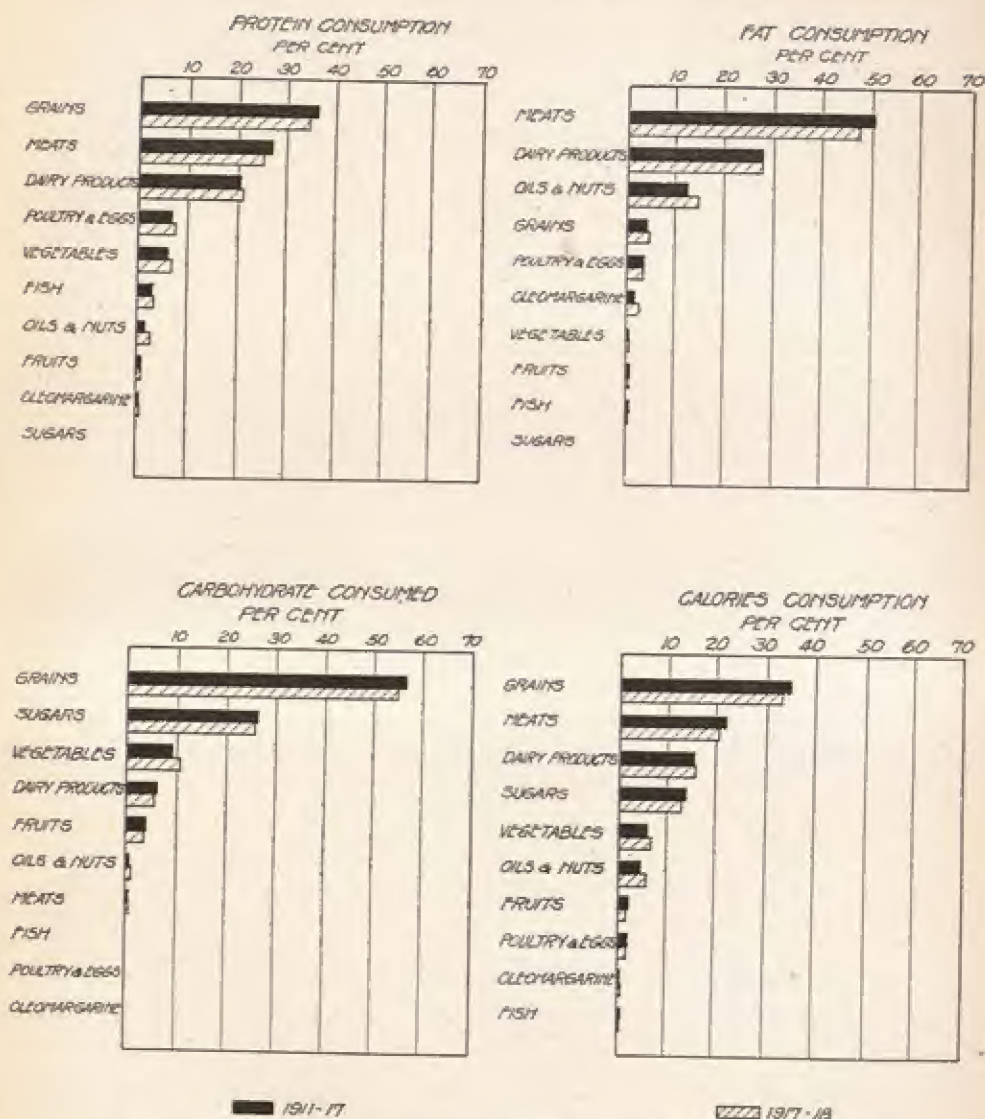


FIG. 4. Showing the percentage contribution of the different great food commodity groups to the nutritional intake of the United States, for (a) six years before our entry into the war, and (b) 1917-18.

etc. But the proportion of the total contributed by the grains and meats is smaller in 1917-18. In other words, the two great com-



modity groups on which the most stress was laid in the conservation campaign show a reduction in the part which they play in national nutrition. The effect of the conservation work will, however, be more clearly shown when we come to the consideration of individual commodities.

Of the fat normally consumed 51 per cent. is furnished by the meats as a group; 27 per cent. by the dairy products; and 12 per cent. by the vegetable oils and nuts. The grains normally furnish 3.98 per cent. of the fat intake and in 1917-18 this rose slightly to 4.16, due to the increased consumption of corn meal.

The sugars stand second in the list as contributors of carbohydrate to consumption, with 26 per cent. of the total, to which 56 per cent. is furnished by the grains. Of the remainder of the carbohydrate intake vegetables normally contribute about 9 per cent., the dairy products 5 per cent., and the fruit 4 per cent.

The energy values of the groups are especially interesting as furnishing a general index of food values. Of the total energy furnished by the human food consumed 35 per cent. comes from the grains, 22 per cent. from the meats, 15 per cent. from the dairy products and 13 per cent. from the sugars. These four groups make up about 85 per cent. of the total energy value of all the food

TABLE VIII.

SHOWING THE CHANGES IN FOOD CONSUMPTION IN THE UNITED STATES IN 1917-18 AS COMPARED WITH THE AVERAGE ANNUAL CONSUMPTION IN SIX PRECEDING YEARS (MILLIONS OF CALORIES).

Group.	Increase of Consumption in 1917-18 Over 6 Year Average.	Decrease of Consumption in 1917-18 Under 6 Year Average.	Percentage Increase.	Percentage Decrease.
Grains.....	512,058	—	1.14	—
Meats.....	18,653	—	.07	—
Dairy products.....	1,176,387	—	5.93	—
Sugars.....	742,534	—	4.32	—
Vegetables.....	2,089,106	—	30.23	—
Oils and nuts.....	1,834,887	—	29.37	—
Fruits.....	—	139,936	—	4.89
Poultry and eggs.....	27,951	—	1.07	—
Oleomargarine.....	627,874	—	115.69	—
Fish.....	—	1,090	—	.20
Total.....	6,888,424	—	5.30	—
Population.....	5,662,979	—	5.73	—

consumed. Vegetables contribute only about 5 per cent., fruit and poultry about 2 per cent. each, and vegetable oils and nuts nearly 5 per cent.

On the basis of Table VII. it is of interest to examine somewhat more carefully the changes in consumption rate in 1917-18 as compared with the average of the six preceding years. Such a comparison is made in Table VIII. and shown graphically in Fig. 5.

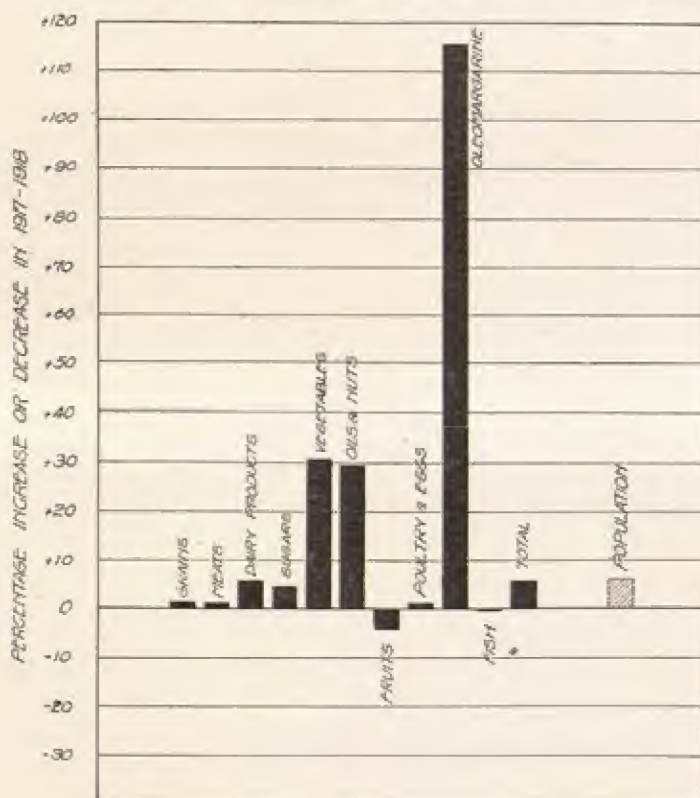


FIG. 5. Diagram showing the increase or decrease in food consumption in 1917-18 as compared with the average of the preceding six years.

From Table VIII. and the diagram it is observed that the total increase in human food consumption in 1917-18 was less (nearly  $\frac{1}{2}$  per cent.) proportionately than in the increase in population, both being compared with the average of the six preceding years. The



consumption of meats practically did not increase at all, and the consumption of grains only about 1 per cent.

The great increases were first in the consumption of vegetables and oils and nuts, amounting to 30 per cent. in the one case and 29 per cent. in the other, and second in oleomargarine where the consumption increased nearly 116 per cent. in 1917-18 over the average of the preceding six years. In the case of vegetables and oils and nuts the increased consumption in 1917-18 is probably to be attributed largely to the activity of the Food Administration in urging

TABLE IX.

CONSUMPTION OF PROTEIN IN HUMAN FOOD, PRIMARY AND SECONDARY, IN THE UNITED STATES, ARRANGED BY COMMODITIES IN ORDER OF MAGNITUDE.

Order No.	Commodity.	Average for the Six Years, 1911-12 to 1916-17.			For 1917-18.		
		Absolute Consumption of Protein (Metric Tons).	Percentage Consumption.	Cumulative Per Cent.	Absolute Consumption of Protein (Metric Tons).	Percentage Consumption.	Cumulative Per Cent.
1	Wheat.....	1,054,548	28.85	28.85	940,543	24.85	24.85
2	Dairy products...	744,784	20.38	49.23	788,969	20.85	45.70
3	Beef.....	528,709	14.47	63.70	539,703	14.26	59.96
4	Pork.....	392,665	10.74	74.44	378,799	10.01	69.97
5	Poultry and eggs..	246,178	6.74	81.18	248,772	6.57	76.54
6	Corn.....	202,717	5.55	86.73	242,395	6.40	82.94
7	Potatoes.....	114,598	3.14	89.87	143,167	3.78	86.72
8	Fish.....	84,852	2.32	92.19	105,578	2.79	89.51
9	Legumes.....	69,669	1.91	94.10	85,021	2.25	91.76
10	Nuts.....	46,819	1.28	95.38	81,939	2.16	93.92
11	Mutton.....	43,712	1.20	96.58	65,088	1.72	95.64
12	Other cereals.....	30,471	.83	97.41	36,668	.97	96.61
13	Other vegetables..	30,137	.82	98.23	30,725	.81	97.42
14	Rice.....	17,231	.47	98.70	28,298	.75	98.17
15	Rye.....	11,174	.31	99.01	24,597	.65	98.82
16	Cocoa.....	11,020	.30	99.31	20,083	.53	99.35
17	Apples.....	8,719	.24	99.55	9,283	.25	99.60
18	Other fruits.....	7,620	.21	99.76	7,458	.20	99.80
19	Bananas.....	6,979	.19	99.95	5,771	.15	99.95
20	Oranges.....	1,647	.04	99.99	1,808	.05	100.00
21	Oleomargarine...	838	.02	100.01	1,109	.03	100.03
22	Sugars.....	455	.01	100.02	439	.01	100.04
—	Oils.....	0	0	100.02	0	0	100.04
	Total.....	3,654,572	—	—	3,784,690	—	—

the consumption of these commodities to afford a relief of the pressure on wheat and meat products. In the case of oleomargarine the increased consumption is clearly due entirely to a favorable

price differential as compared with butter and lard, taking into account palatability.

The only two great commodity groups showing decreases in consumption in 1917-18 are fruits and fish. In both cases the result is probably to be explained by price influences, taken together with palatability and popular ideas as to relative necessity in the diet. For example the price of meat may rise relatively much more than that of fruits or fish without leading to any reduction in consump-

TABLE X.

CONSUMPTION OF FAT IN HUMAN FOODS, PRIMARY AND SECONDARY, IN THE UNITED STATES, ARRANGED BY COMMODITIES IN ORDER OF MAGNITUDE.

Order No.	Commodity.	Average for the Six Years 1911-12 to 1916-17.			For 1917-18.		
		Absolute Consumption of Fat (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.	Absolute Consumption of Fat (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.
1	Pork.....	2,024,236	39.57	39.57	2,045,653	37.33	37.33
2	Dairy products...	1,465,918	27.49	67.06	1,505,129	27.46	64.79
3	Oils.....	505,201	9.88	76.94	554,851	10.13	74.92
4	Beef.....	505,033	9.87	86.81	513,596	9.37	84.29
5	Poultry and eggs...	173,349	3.39	90.20	179,337	3.27	87.56
6	Corn.....	97,355	1.90	92.10	175,220	3.20	90.76
7	Nuts.....	92,348	1.81	93.91	125,024	2.28	93.04
8	Wheat.....	91,929	1.80	95.71	118,845	2.17	95.21
9	Mutton.....	65,499	1.28	96.99	81,835	1.49	96.70
10	Oleomargarine.....	57,065	1.13	98.12	47,273	.86	97.56
11	Cocoa.....	25,836	.51	98.63	46,853	.86	98.42
12	Fish.....	18,096	.35	98.98	23,104	.42	98.84
13	Other cereals.....	12,391	.24	99.22	17,866	.33	99.17
14	Other vegetables...	9,935	.19	99.41	12,586	.23	99.40
15	Apples.....	8,629	.17	99.58	7,953	.15	99.55
16	Other fruits.....	7,713	.15	99.73	7,451	.14	99.69
17	Potatoes.....	6,366	.12	99.85	7,325	.13	99.82
18	Legumes.....	4,824	.09	99.94	6,767	.12	99.94
19	Bananas.....	3,488	.07	100.01	3,256	.06	100.00
20	Rye.....	1,479	.03	100.04	2,885	.05	100.05
21	Rice.....	431	.01	100.05	767	.01	100.06
22	Oranges.....	411	.01	100.06	278	.01	100.07
—	Sugars.....	0	0	100.06	0	0	100.07
Total.....		5,115,279	—	—	5,479,939	—	—

tion, owing to the general belief that meat is a more necessary article of diet than the other two sorts of food mentioned.

We may next consider the gross consumption of individual commodities on the same plan that has just been used in handling the groups. The data are given in Tables IX. to XII. inclusive. In



these tables it will be noted that the cumulated percentage columns run to more than 100 per cent. by trifling amounts. This is to take care of the item "other meat products" which appears in the net export table but not in production (in basic tables not here given). In the main consumption table it is carried into the subtotal "Meats," but does not appear as a separate item, because of the impossibility of calculating it as such.

TABLE XI.

CONSUMPTION OF CARBOHYDRATE IN HUMAN FOODS, PRIMARY AND SECONDARY, IN THE UNITED STATES, ARRANGED BY COMMODITIES IN ORDER OF MAGNITUDE.

Order No.	Commodity.	Average for the Six Years, 1911-12 to 1916-17.			For 1917-18.		
		Absolute Consumption of Carbohydrate (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.	Absolute Consumption of Carbohydrate (Metric Tons).	Percentage Consumption.	Cumulated Per Cent.
1	Wheat.....	6,944,794	42.3125	42.3125	6,195,182	36.1534	36.1534
2	Sugars.....	4,193,095	25.5473	67.8598	4,374,194	25.5266	61.6800
3	Corn.....	1,805,364	11.0008	78.8606	2,155,310	12.5778	74.2578
4	Potatoes.....	935,881	5.7020	84.5626	1,169,204	6.8232	81.0810
5	Dairy products.....	899,691	5.4815	90.0441	917,169	5.3524	86.4334
6	Apples.....	312,589	1.9045	91.9486	398,275	2.3242	88.7576
7	Other vegetables.....	303,868	1.8514	93.8000	352,857	2.0592	90.8168
8	Legumes.....	182,193	1.1095	94.9095	303,428	1.7707	92.5875
9	Other fruits.....	171,574	1.0454	95.9549	284,668	1.6612	94.2487
10	Rice.....	170,151	1.0367	96.9916	277,293	1.6177	95.8664
11	Other cereals.....	159,113	.9694	97.9610	268,425	1.5665	97.4329
12	Rye.....	129,318	.7879	98.7489	219,437	1.2794	98.7123
13	Bananas.....	111,628	.6801	99.4290	92,328	.5388	99.2511
14	Nuts.....	35,571	.2167	99.6457	63,054	.3680	99.6191
15	Oranges.....	31,696	.1931	99.8388	39,177	.2286	99.8477
16	Cocoa.....	21,526	.1312	99.9700	21,360	.1247	99.9734
17	Pork.....	2,749	.0167	99.9867	2,859	.0167	99.9891
18	Beef.....	1,707	.0104	99.9971	1,577	.0092	99.9983
19	Mutton.....	484	.0029	100.0000	315	.0018	100.0001
20	Fish.....	20	.0001	100.0001	25	.0001	100.0002
—	Oils.....	0	0	100.0001	0	0	100.0002
—	Poultry and eggs.....	0	0	100.0001	0	0	100.0002
—	Oleomargarine.....	0	0	100.0001	0	0	100.0002
	Total.....	16,413,087			17,135,813		

The data of Tables IX. to XII. inclusive are shown, exhibited graphically, in Figs. 6 to 9.

Taking first the protein consumption, as given in Table IX., we see that wheat stands at the head of the list as a source of protein for the population of this country, contributing nearly 28 per cent.

TABLE XII.

CONSUMPTION OF HUMAN FOODS, PRIMARY AND SECONDARY, IN THE UNITED STATES, IN TERMS OF CALORIC VALUE, ARRANGED BY COMMODITIES IN ORDER OF MAGNITUDE.

Order No.	Commodity.	Average for the Six Years, 1911-12 to 1916-17.			For 1917-18.		
		Absolute Consumption (Million Calories).	Percentage Consumption.	Cumulated Per Cent.	Absolute Consumption (Million Calories).	Percentage Consumption.	Cumulated Per Cent.
1	Wheat.....	33,657,299	25.90	25.90	30,021,979	21.94	21.94
2	Pork.....	20,453,649	15.74	41.64	21,010,397	15.36	37.30
3	Dairy products.	19,834,010	15.26	56.90	20,594,616	15.05	52.35
4	Sugars.....	17,196,595	13.24	70.14	17,939,129	13.11	65.46
5	Corn.....	9,141,678	7.03	77.17	10,938,521	7.99	73.45
6	Beef.....	6,892,851	5.30	82.47	7,017,398	5.13	78.58
7	Oils.....	4,700,590	3.62	86.09	5,455,418	3.99	82.57
8	Potatoes.....	4,366,750	3.36	89.45	5,162,528	3.77	86.34
9	Poultry and eggs	2,620,311	2.02	91.47	2,648,262	1.94	88.28
10	Other vegetables	1,465,344	1.13	92.60	2,262,988	1.65	89.93
11	Apples.....	1,403,750	1.08	93.68	1,927,964	1.41	91.34
12	Nuts.....	1,196,911	.92	94.60	1,904,998	1.39	92.73
13	Legumes.....	1,077,932	.83	95.43	1,638,716	1.20	93.93
14	Other cereals...	893,383	.69	96.12	1,381,039	1.01	94.94
15	Other fruits...	800,831	.62	96.74	1,299,820	.95	95.89
16	Mutton.....	791,032	.61	97.35	1,205,454	.88	96.77
17	Rice.....	774,430	.60	97.95	1,170,593	.86	97.63
18	Rye.....	590,475	.45	98.40	994,221	.73	98.36
19	Oleomargarine.	542,719	.42	98.82	678,641	.50	98.86
20	Fish.....	534,509	.41	99.23	553,498	.40	99.26
21	Bananas.....	519,109	.40	99.63	533,419	.39	99.65
22	Cocoa.....	371,769	.29	99.92	429,360	.31	99.96
23	Oranges.....	138,850	.11	100.03	93,569	.07	100.03
Total.....		129,931,314			136,819,738		

normally to the total. Dairy products are second with 20 per cent. of the total. Beef with 14 per cent. and pork with 11 per cent. stand next. The other commodities contributing more than 2 per cent. to the total protein intake of the population are, in the order named: Poultry and eggs, corn, potatoes, and fish. Taken together, these eight commodities furnish 92 per cent. of the total protein intake. We see that a very few commodities furnish a very large percentage of the nutritional intake. This fact, in and of itself, helps enormously towards the possibility of making a study such as this substantially accurate in its results. It is clear that the minor items omitted from our calculations have no significance in the final general result. If four food commodities furnish nearly 75 per cent. of the total protein ingested, it is obvious that a large error,



or even the entire omission, of single ones of the other minor items can have but little effect.

Comparing the order of the commodities in 1917-18 with the average of the six preceding years, it is seen that the only change of position among the eight commodities normally furnishing over

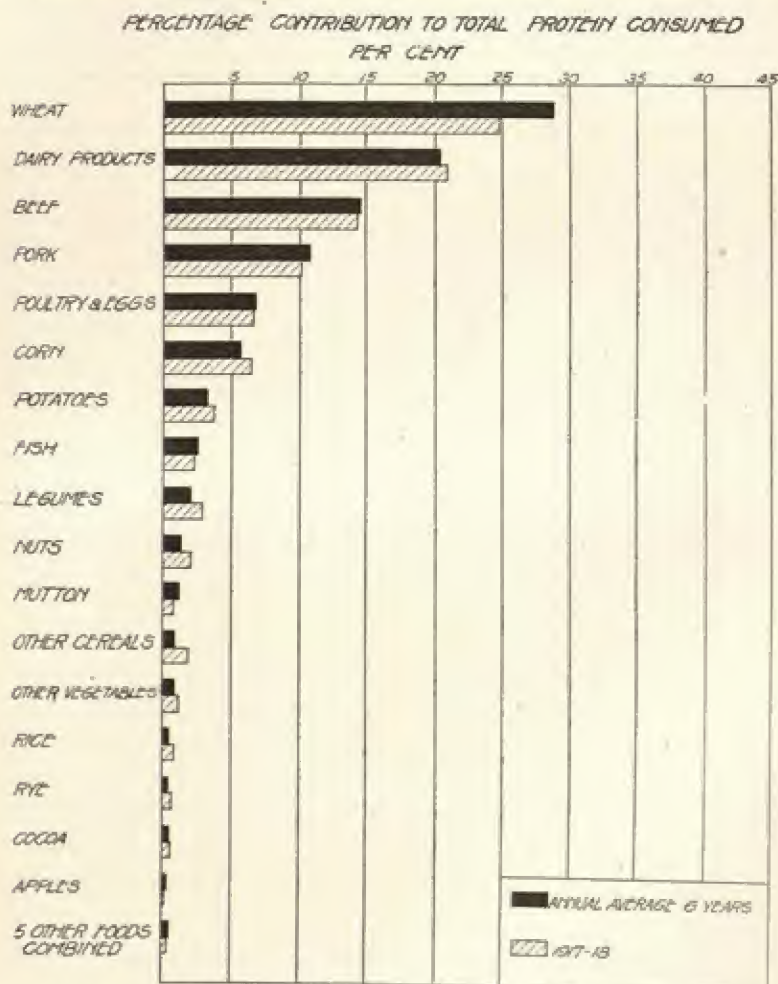


FIG. 6. Diagram showing the percentage of the total protein consumed in the United States contributed by each of 23 commodities. The solid bars denote the average consumption in the six years preceding our entry into the war. The cross-hatched bars denote the consumption in 1917 and 1918.

90 per cent. of the protein is in respect of the last one on the list, namely, fish. In 1917-18 the legumes (beans and peas) moved up to the eighth place and fish moved to the ninth place.

Turning to the fat consumption, it is seen that approximately 40 per cent. of the total fat in the nutritional intake of this country

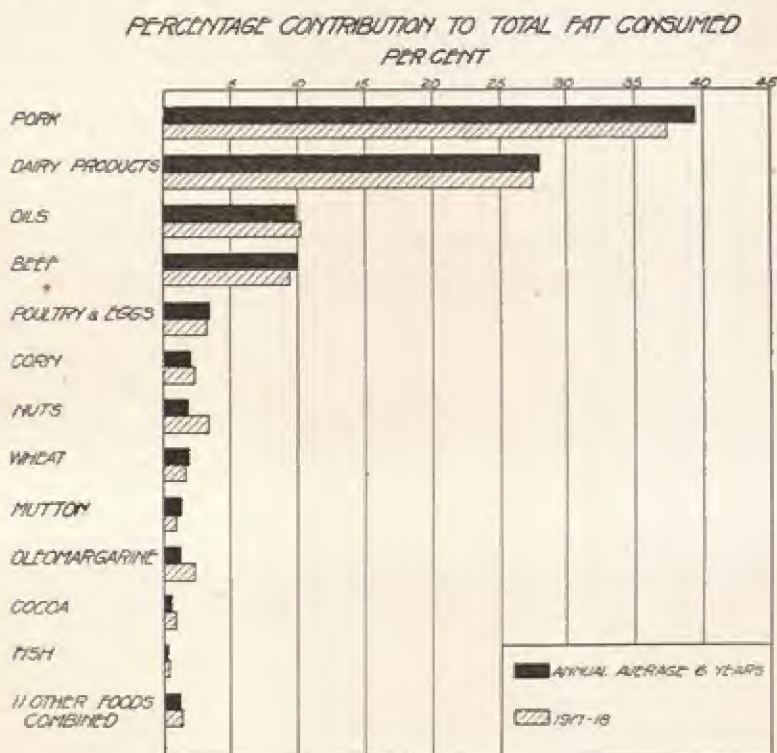


FIG. 7. Diagram showing the percentage of the total fat consumed in the United States contributed by each of 23 commodities. The solid bars denote the average consumption in the six years preceding our entry into the war. The cross-hatched bars denote consumption in 1917 and 1918.

comes from pork and its products. The hog is in a class by itself as a source of fat for human nutrition, with the population of this country. Dairy products stand second in the list, with approximately  $27\frac{1}{2}$  per cent. of the total. After the dairy products there is a considerable drop in percentage contribution as we pass to the next item on the list, namely, the vegetable oils, which normally



furnish only about 10 per cent. of the fat intake. Beef contributes almost exactly the same percentage. The four commodities named together furnish nearly 87 per cent. of the total fat intake. Only

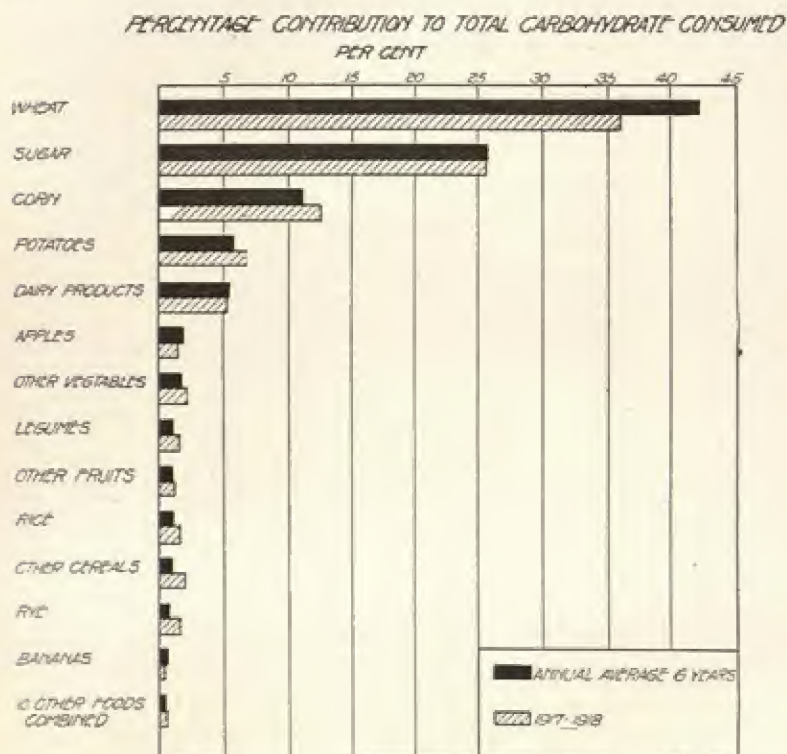


FIG. 8. Diagram showing the percentage of the total carbohydrate consumed in the United States contributed by each of 23 commodities. The solid bars denote the average consumption in the six years preceding our entry into the war. The cross-hatched bars denote the consumption in 1917 and 1918.

one other commodity group—namely, poultry and eggs—furnishes more than 2 per cent. normally.

In 1917-18 there are some changes of significance in the relative position of the commodities as fat contributors. The first four items, pork, dairy products, oils and beef, stand in the same order in 1917-18 as in the six years preceding. Nuts moved up in 1917-18 to the fifth place from the seventh, which they had occupied

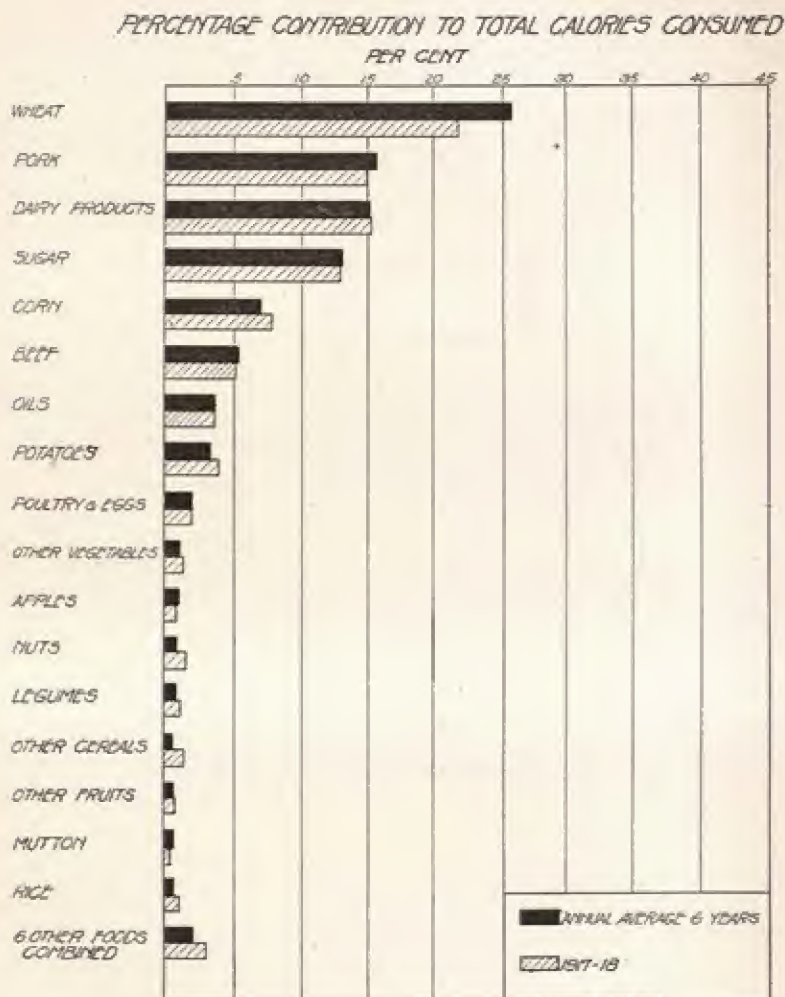


FIG. 9. Diagram showing the percentage of the total energy value of the food consumed in the United States contributed by each of 23 commodities. The solid bars denote the average consumption in the six years preceding our entry into the war. The cross-hatched bars denote the consumption in 1917 and 1918.

before. Oleomargarine moved from the tenth place to the seventh. Corn, in spite of the increased consumption in 1917, dropped from the sixth place to the eighth in percentage contribution. Twelve of



the great commodity groups before our entry into the war, and thirteen in 1917-18, contribute less than 1 per cent. to the total fat intake.

In carbohydrate consumption wheat stands at the head of the list with over 24 per cent. normally. The sugars stand second with about 26 per cent., and corn with 11 stands next. These three commodities, together with potatoes and the dairy products, contribute altogether 90 per cent. of the carbohydrate intake. There is no change in the relative position of the commodities falling in the 90 per cent. group in 1917-18 as compared with the average of the six preceding years.

A noteworthy feature of this Table XI., dealing with carbohydrates is the relative position of the sugars. Many persons regard sugar as a pleasant but not essential part of the dietary. It is obvious enough that this is a mistaken point of view. Any commodity which furnishes nearly 26 per cent. of the carbohydrate intake of the population must be regarded as an important essential. To get an idea of the importance of the sugar relatively it is only necessary to compare it with some of the items farther down in the table. For example, we see that the sugars contribute more than twenty times as much to the carbohydrate intake of the nation as does rice.

In Table XII. we get a summarized view of the general nutritional importance of the several food commodities, because here we are dealing with the energy content as measured in calories. The order of the products in this table may be taken as the general order of nutritional significance of the great staple foods in this country. Wheat stands at the head of the list, contributing nearly 26 per cent. to the total. Pork comes next with normally 16 per cent., and dairy products third with 15 per cent., and the sugars fourth with 7 per cent. Then follow corn, beef, the vegetable oils, potatoes, poultry and eggs. These nine commodity groups together make up over 91 per cent. of the total nutritional intake of the population. The smallest contribution to the total nutrition is made by oranges, furnishing about  $\frac{1}{10}$  of 1 per cent. to the total. Bananas and fish furnish only about  $\frac{4}{10}$  of 1 per cent. of the total, and rye and rice only a little more.

The changes in 1917-18, as compared with the average in the

six preceding years, as shown in Table XII., are extremely interesting. The figures show in much more detail than any that we have had hitherto the precise effects of the conservation and substitution campaign of the United States Food Administration during 1917-18. While wheat normally contributes 25.9 per cent. of the total nutritional intake (as measured by energy value), in 1917-18 it contributed but 21.9 per cent. To go farther down the table, rice, which normally contributed but 0.6 of 1 per cent. to the total nutritional intake, contributed 1 per cent. in 1917-18.

The changes in consumption, as indicated in Table XII., are of such great interest that it is worth while to examine them more in detail. To this end a table on the same plan as Table VII. is shown.

TABLE XIII.

SHOWING THE CHANGES IN FOOD CONSUMPTION IN THE UNITED STATES IN 1917-18 AS COMPARED WITH THE AVERAGE ANNUAL CONSUMPTION OF SIX PRECEDING YEARS FOR 23 STAPLE HUMAN FOODS (MILLIONS OF CALORIES).

Commodity.	Increase of Consumption in 1917-18 Over 6 Year Average.	Decrease of Consumption in 1917-18 Under 6 Year Average.	Percentage Increase.	Percentage Decrease.
Wheat.....	—	3,635,320	—	10.80
Pork.....	140,967	—	.69	—
Dairy products.....	1,176,387	—	5.93	—
Sugar.....	742,534	—	4.32	—
Corn.....	1,796,843	—	19.66	—
Beef.....	224,547	—	3.26	—
Oils.....	461,938	—	9.83	—
Potatoes.....	1,088,668	—	24.93	—
Poultry and eggs.....	27,951	—	1.07	—
Other vegetables.....	439,654	—	—	—
Apples.....	—	198,296	—	14.13
Nuts.....	1,066,077	—	89.07	—
Legumes.....	560,784	—	52.02	—
Other cereals.....	1,034,581	—	115.80	—
Other fruits.....	193,390	—	24.15	—
Mutton.....	—	237,534	—	30.03
Rice.....	606,609	—	78.33	—
Rye.....	709,345	—	120.13	—
Oleomargarine.....	627,874	—	115.69	—
Fish.....	—	1,090	—	.20
Bananas.....	—	89,749	—	17.29
Cocoa.....	306,872	—	82.54	—
Oranges.....	—	45,281	—	32.61
Total net increase.....	6,888,424	—	5.30	—
Population.....	5,662,979	—	5.73	—



The data of Table XIII. are exhibited graphically in Fig. 10. In this diagram the total length of the bars from the O line shows the total percentage increase or decrease in consumption in 1917-18 as compared with the preceding six years. The cross-hatched portion of each bar shows the percentage increase in population, and therefore the part of the increased consumption to be expected as

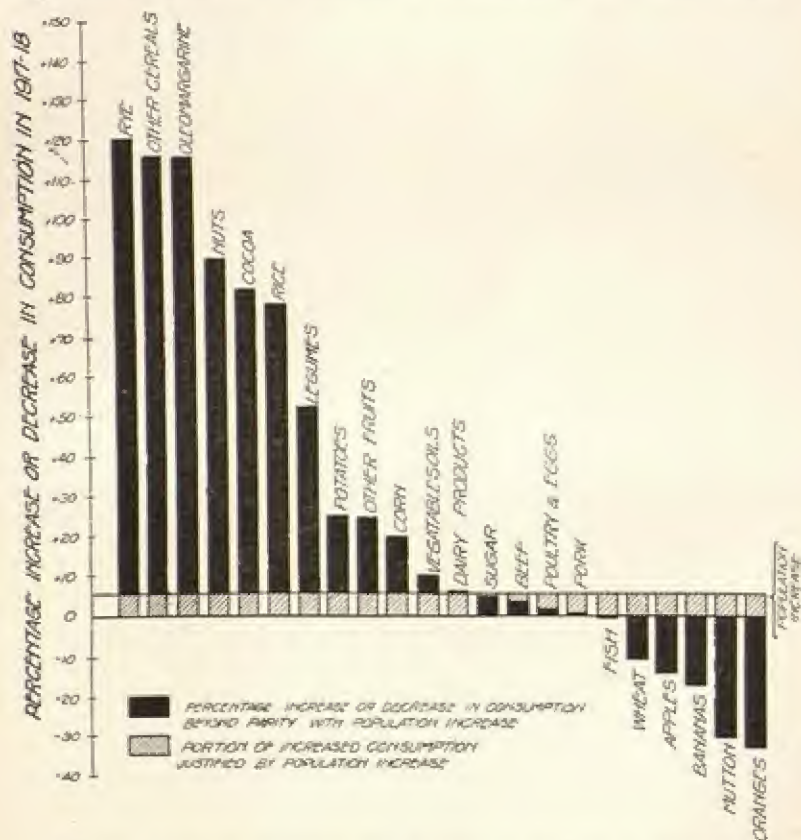


FIG. 10. Showing the percentage increase or decrease in consumption in 1917-18 as compared with the annual average of the six years preceding. For explanation see text.

a result of population increase. Where the black bar is below the top of the cross-hatched population bar it means a conservation. Thus the true conservation on wheat amounted to  $10.80 + 5.73 = 16.53$  per cent. of the normal average consumption.

The table and diagram bring out very clearly the effectiveness of the Food Administration's campaign for conservation and substitution in foods. It will be noted at once that the commodities showing great increases in consumption in 1917-18 over the preceding years are, for the most part, those which the Food Administration urged to be substituted for articles of which the supply was less abundant, and for which the needs of the Allies were greater. Thus, rye, which constituted the most popular of the substitutes for wheat in the public mind, shows the greatest increased consumption in 1917-18. Next to it stands the "Other cereals" of our classification, including barley and buckwheat. Nuts, rice and the vegetables generally show increases beyond the population increase, showing that the people very generally followed the suggestions of the Food Administration to consume more of these products and save wheat. The articles on which the Food Administration most strongly urged conservation—namely, wheat, beef, mutton, pork and the sugars—all show either a consumption actually below the normal average, or else a very slight absolute increase well below the population percentage increase. In either case a real and substantial conservation is, of course, shown. The decrease in consumption of the most popular fruits, oranges, apples and bananas is largely if not entirely explained by high prices for these products.

We get now to the most interesting stage of any discussion of food, namely, the per capita per day consumption. Calculating the results on this basis puts them in a form where we may form a better judgment of their meaning and compare them with accepted dietary standards. In this connection it is to be remembered that hitherto we have had no careful studies on a per capita basis of the actual nutritional intake of the population as a whole. All dietary standards are based not on the actual practice of the whole population, but rather upon dietary studies made on restricted groups of selected individuals. While a very large number of such studies have been made by the United States Department of Agriculture particularly from ten to twenty years ago, it must be obvious that since such studies are made on selected small groups they can only inferentially give any picture of what is taking place in the population as a whole. The theory of random sampling makes it clear



that any inference from dietary studies, as they have been carried on, to the whole population rests on an exceedingly dubious foundation. It will therefore be of great interest to compare the results of the present careful investigation of the population as a whole with the results of previous dietary studies.

In reducing consumption data to a per capita basis it would obviously be foolish to take the actual total population as a base, for the reason that the amount of food consumed changes with the age of the individual, particularly in early life. On account of this fact the usual practice in computations of this kind is to reduce, not to a per capita basis, but to an adult man basis. In doing this a fractional factor is used to multiply the number of individuals of certain lower ages, the magnitude of the factor being proportional to the relation which the nutritional intake of the individual at the younger age bears to that of an average adult man.

In the present study the following age-intake factors have been used:

Age in Years.	Man Value Factor.
0-5 .....	0.50
6-13 .....	0.77
14-18, male .....	1.00
14-18, female .....	0.83
19 on, male .....	1.00
19 on, female .....	0.83

The man factor values here used have been adopted after careful study of the subject. They differ in detail somewhat from those adopted by English physiologists in similar calculations, but in the net end result come to much the same thing.

Applying these factors to the total population of the United States, and assuming that the age distribution of the population is the same in each of the years studied, we get the population in terms of adult men as set forth in Table XIV. for the midyear point of each of the years included in this study. The population equivalents in Table XIV. are used for the base for the per capita per diem calculations which follow.

Before entering on the detailed discussion of per capita consumption figures it is well to recall a fact which is liable to escape attention, unless special attention is called to it. This is the fact

TABLE XIV.

POPULATION OF CONTINENTAL UNITED STATES IN TERMS OF ADULT MEN.

Year.	Population Equivalent in Adult Men, January 1.
1912 .....	79,571,000
1913 .....	80,930,000
1914 .....	82,289,000
1915 .....	83,648,000
1916 .....	85,007,000
1917 .....	86,366,000
1918 .....	87,724,000

that the final figures in this paper, which are called "consumption figures," really include something more than consumption in a nutritional sense. They include the food actually eaten plus that which is wasted by loss in cooking, in garbage, etc. It is necessary to be entirely clear on this point. In calculating the nutrients in the intermediate calculations use has been made of factors which allowed for *inedible* refuse, so that all of the inedible portion of the foods as produced or imported have already been deducted in our calculations up to this point. Furthermore, gross losses from storage, spoilage, transportation, etc., have been deducted. Even after all these deductions have been made, however, it is obvious that there is still a considerable amount of loss and wastage of strictly edible material, which might be saved and consumed under a theoretically ideal system of preparing food for the table plus a conscientious ingestion of every bit of edible material. Of course, as a matter of fact, neither of these theoretically ideal conditions at all prevail. There is a considerable loss of nutrient values in the process of cooking as ordinarily practiced. This loss is undoubtedly greater for fats than for any other of the nutrients. It is a troublesome and time-consuming process for the housewife to conserve and utilize all of the fat which gets melted and floats about in the water in which foods are cooked, or adheres to the utensils in which they are cooked. Nor, in the minds of most people, is there any necessity or desirability of saving this fat. In fact, a great many people in this country object very strongly to what they designate as "greasy cooking." Consequently, floating fat of soup stock is skimmed off and thrown away in the vast majority of instances.



The result is that in calculations made in the way those of this study have been made, which include the total nutrient value in the edible portion of food materials, after deducting inedible waste and the losses which accrue up to the time the food reaches the consumer, there is bound to be an apparently high consumption of fats. The figures here presented are really statements of consumption plus edible waste and should be so regarded.

Another important factor is that of edible waste in garbage: that is to say, the uneaten portion of the prepared food which is edible and might be consumed, but is not for reasons of taste, over-estimation of ingestive capacity, etc.

It is quite impossible to arrive at any accurate estimate of what the amount of losses of nutrients in cooking and in avoidable wastage of edible material is. On the first point it would be extremely difficult ever to gather accurate data because the practice of housewives and cooks varies so enormously in this regard. That a great deal can be accomplished in reducing the amount of edible material going into the garbage can has been demonstrated with both the civilian and the Army population of the United States during the past year.<sup>10</sup>

The recent study of Murlin (*loc. cit.*) gives the data regarding edible waste obtained from the nutritional surveys of the training camps. The average figure for 213 messes show that 7 per cent. of the protein supplied was wasted, 9 per cent. of the fat and 6 per cent. of the carbohydrate. Because of special conditions surrounding the investigation, however, and because of the differences of camp life, these figures are not at all applicable to civilian conditions.

Looking at the matter from the national point of view, it seems probable that of the protein in human foods left in the country for consumption in the statistical sense, it is safe to say that 5 per cent. is lost in edible wastage; of the fat left in the country for consumption as human food, it is believed that at least 25 per cent. is lost through wastage. This figure seems large, but it probably under-

<sup>10</sup> Pearl, R., "Statistics of Garbage Collection and Garbage Grease Recovery in American Cities," *Jour. Ind. Eng. Chem.*, Volume 10, page 927, 1918, and Murlin, J. H., "Diet of the U. S. Army Soldier in the Training Camp," *Jour. Amer. Med. Assoc.*, Vol. 71, pp. 950-951, 1918.

estimates rather than overestimates the fact. Of the carbohydrates, probably there is 20 per cent. of edible wastage.

The total statistical consumption (ingestion plus edible wastage) of human food in the United States, by years from 1911 to 1918, is shown on an "adult man" per capita basis in Table XV.

TABLE XV.  
SUMMARY OF CONSUMPTION PER ADULT MAN.

Year.	Protein.		Fat.		Carbohydrate.		Calories.	
	Per Annum (Kilos).	Per Day (Grams).	Per Annum (Kilos).	Per Day (Grams).	Per Annum (Kilos).	Per Day (Grams).	Per Annum (Kilos).	Per Day (Grams).
1911-12.....	44.70	122	62.12	170	195.48	536	1,563.450	4,283
1912-13.....	44.04	121	60.44	166	198.68	544	1,558.232	4,269
1913-14.....	45.08	124	60.22	165	209.25	573	1,591,621	4,361
1914-15.....	43.05	118	63.42	174	193.42	530	1,560,326	4,275
1915-16.....	44.48	122	61.22	168	200.48	549	1,574,621	4,314
1916-17.....	43.01	118	62.45	171	189.94	520	1,536,833	4,211
1917-18.....	43.14	118	62.47	171	195.34	535	1,559,661	4,273
Average, whole period.....	43.91	120	61.78	169	197.45	541	1,565.075	4,288
Average, 1911-12 to 1916-17.....	44.05	121	61.65	169	197.82	542	1,566.032	4,290

Applying the estimated percentage deductions for edible wastage stated above to the per capita average for the whole period we have the following results for ingested human food:

- 114 grams protein per man per day,
- 127 grams fat per man per day,
- 433 grams carbohydrate per man per day,
- 3424 calories per man per day.

These figures are probably very close to the fact as regards protein and carbohydrate. They are undoubtedly somewhat too high still as regards fat, because the edible wastage of this component is higher than the 25 per cent. used. The intention, however, has been to use the most conservative figures in estimating waste.

For purposes of comparison Table XVI. is inserted. This table is based upon certain American dietary studies analyzed in the writer's statistical laboratory.

The general agreement of these results with those set forth in the present study, which were reached by totally different procedure,



is evident. The statistical estimate of per capita protein consumption over the whole population is distinctly higher than in this small group. The fat consumption is higher but not by so large an amount as protein. The farmers and professional men show a higher net energy intake than the general average for the whole country, which would, of course, be expected. Mechanics are a little lower than the average for the country in energy intake.

In any case there is one fact which must not be lost sight of, namely, that while the figures of Table XV. do in fact represent

TABLE XVI.

SUMMARY OF SOME DIETARY STUDIES IN 11 GROUPS AND 116 FAMILIES.

	No. of Families.	Average Yearly Income.	Days per Man.	Per Man per Day.			
				Protein, Grams.	Fat, Grams.	Carbohydrate, Grams.	Energy, Calories.
Mother wage earners....	8	\$ 640	212	105	65	472	2,895
Garment makers.....	7	724	168	109	81	495	3,145
Laborers.....	6	1,497	305	94	102	479	3,210
Retired.....	5	1,647	130	81	121	420	3,095
Clerks (office).....	11	1,934	225	92	120	419	3,125
Mechanics.....	8	2,133	259	97	113	460	3,245
Teachers.....	32	2,150	620	88	125	430	3,195
Professional men.....	17	2,208	438	99	148	438	3,480
Engineers (professional) .	5	2,253	97	85	128	395	3,070
Salesmen.....	5	2,527	121	90	111	405	2,980
Farmers.....	12		384	102	131	506	3,610
Average.....	116	\$1,771 <sup>11</sup>	260	95	113	447	3,185

<sup>11</sup> Average of 104 families (farmers excluded).

ingestion and waste, it still is true, and the constancy of the figures in successive years proves its truth, that to maintain naturally a contented feeling in respect of nutrition the population actually uses up the amounts of nutrients indicated in Table XV. To make these gross consumption figures materially less would require a profound readjustment of the dietary and culinary habits of the people, fixed by centuries of usage. Discussion of the minimum protein, fat and carbohydrate requirements of a nation are in considerable degree academic if they base themselves upon net consumption rather than gross consumption. A considerable excess over any agreed upon minimum *physiological* requirements must always be allowed, be-

cause there will inevitably be, in fact, a margin between actual gross consumption and net physiological ingestion or utilization. The present study, through the figures summarized in Table XV. gives a clearer and probably more nearly exact picture of what this margin between net and gross consumption must be, in a population of the habits of the American people, than has hitherto been available. It may well be theoretically true that a man needs only 75 grams or 50 grams of protein per day to sustain life and health, but in actual

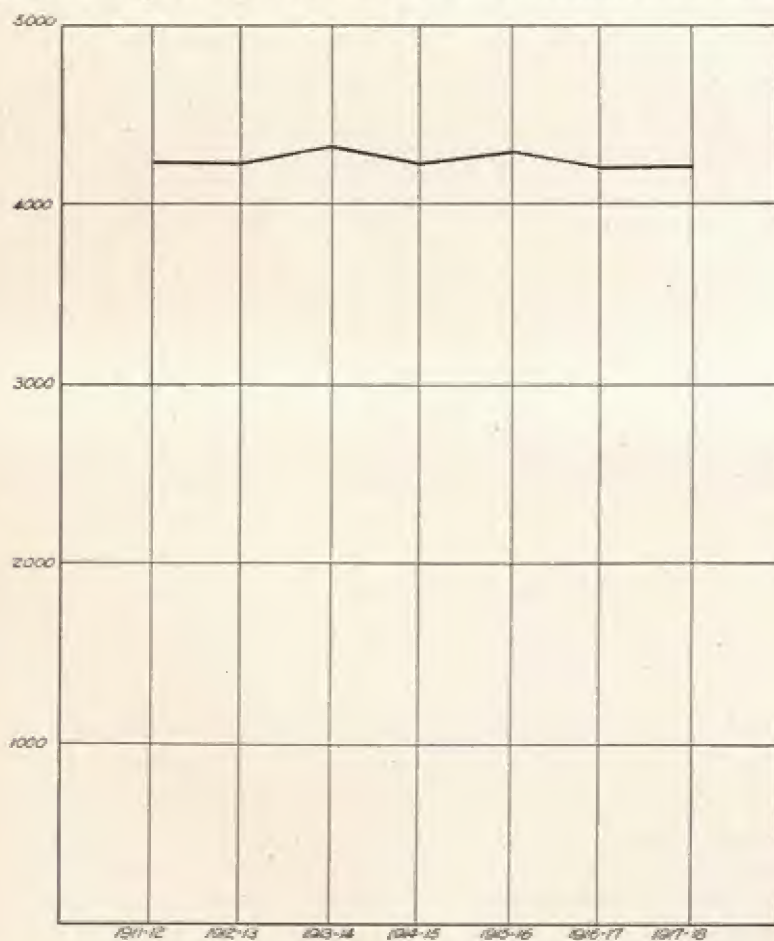


FIG. 11. Diagram showing the energy value in calories of the gross consumption of human food, per adult man per day.



fact the American man uses up, in one way or another, about 120 grams a day. Furthermore, if the last seven years' experience is any criterion, he will continue to use up about 120 grams per diem until such time as his general habits of life are in some manner rather profoundly changed. Doubtless they can be changed. But until they are, one must count on supplying about 120 grams of protein per day to each man equivalent component of the population.

The data of Table XV. for calories are shown graphically in Fig. 11.

From this diagram it is apparent that there has been only a very slight decrease in per capita gross food consumption since 1911. Even this probably does not mean that the population is eating any less, but that because of the gradually rising prices through all this period there has been a narrowing of the margin between gross and net consumption; or, put in another way, there has been a slight reduction in the wastage of edible foods.

#### SUMMARY.

In this paper are presented a portion of the final results of a comprehensive statistical study of the consumption of human food in the United States in the period from July 1, 1911, to July 1, 1918. The results are expressed in terms of nutrients and allowances have been made for losses of edible material in storage by spoilage, in transportation, etc., as well as for inedible refuse, and losses in cooking, garbage, etc. The final net figures are believed to represent with substantial accuracy the course of human food consumption in this country during the period covered. The net result is to show that on a per man per day basis the consumption of nutrients in this population was extremely even and steady during the seven years covered by the investigation. The amount of total nutrients consumed decreased slightly in the period, but the decrease was insignificantly small. The conservation campaign of the Food Administration produced notable changes in 1917-18 in the proportionate contribution of different classes of food materials to the total nutritional intake.

## SELF-LUMINOUS NIGHT HAZE.

By E. E. BARNARD.

(Read April 25, 1919.)

In the *Proceedings of the American Philosophical Society*, Vol. 50 (1911), p. 246, a paper was contributed by the present writer on the subject of "Self-Luminous Night Haze," where observations were given of a kind of luminous, streaky haze seen at night in 1910 and 1911 which seemed to have no connection with the ordinary aurora. Apparently this is a little-known phenomenon. It is well worthy, however, of record and study. The only reference to it that I have found, and it was not known to me at the time of my previous paper, is an account of what was probably the same phenomenon by T. W. Backhouse, who gives occasional records of it in a long paper on the aurora, under the name of "irregular auroras," as far back as December 13, 1862. I will quote his entire reference to the phenomena as given in No. II, p. 109, *Publications of West Hendon House Observatory*, Sunderland, England. "'irr.' means a night when the aurora was only an irregular one, not perceptibly of a magnetic character; I do not know whether these are true auroras or not. They consist of bands and patches of light, the positions and direction of which have no particular relation to either the magnetic declination or dip; they appear to lie in a horizontal stratum, but differ from clouds in being self-luminous and transparent, and also not exactly like any kind of cloud in appearance, and I should think they are at a greater height. They do not appear specially in the north. As auroras of this class are always faint, their spectrum proves little; but I have never made out that it was more than a continuous one. An examination of this table, however, shows that these irregular auroras are more frequent about the time of the maximum of sun-spots than at the minimum, which goes towards proving that they are of the same magnetic nature as the ordinary auroras." Mr. Backhouse did not seem to notice that



this luminous matter is perhaps only ordinary thin haze which, from an unknown cause, is sometimes luminous at night. I believe this same haze is also present in the daytime.

In my previous paper to the Society attention was called to the fact that the objects observed by me did not seem to have any connection with the luminous night clouds of O. Jesse of twenty-five or thirty years previous. His objects were at very great altitudes, some fifty-two miles above the earth's surface, and were visible by direct sunlight which shone on them long after it had ceased to illuminate the ordinary clouds. They were therefore not self-luminous. They were only seen at the times of the equinoxes. The present observations refer to objects entirely self-luminous which are seen in all parts of the sky where sunlight could not reach them, and appear to be at no greater elevation than the higher clouds.

It is only during short periods that the luminous condition of this haze seems to be of frequent occurrence. Apparently it will be absent for a year or so and then for a short time there will be a great amount of it. In 1911 there were frequent displays of it during the spring, summer and autumn, but from 1911, September 22, until 1915, July 2, I have no record of it, though a lookout was always kept for it. It was frequent in the summer and fall of 1910 and also in the spring of 1911. Its prevalence seems to be independent of any auroral conditions. There are a few records of aurora when the haze was present, but only one case in which a large auroral disturbance seems to have been nearly coincident with it. One is impressed with the idea that it is not necessarily an auroral phenomenon and that an appearance of it during an aurora is perhaps purely accidental. Whether this luminous appearance of what is undoubtedly haze, is due to electric conditions or to phosphorescence of some kind does not seem clear.

Sometimes it appears in rather narrow strips several degrees wide and many degrees long; sometimes the form is that of broad sheets covering a large part of the sky. Often both these forms are present at the same time. On one or two occasions I have taken it for the zodiacal light in the east until its motion revealed its true nature. When seen at the eastern horizon it has at times produced the effect of dawn. It is frequently brighter than the Milky Way. From

this it appears that the phenomenon is really conspicuous when seen under good conditions. It seems to have no preference for any special part of the sky. The motion is always easterly. The density of this haze is not great enough to hide the brighter stars over which it passes. In fact, it does not differ from ordinary haze except in being self-luminous. There does not seem to be any fluctuation or pulsation in its light. Under proper conditions it is visible at all hours of the night and in all parts of the sky. Sometimes it is very faint and has to be looked for; at other times it is conspicuous. Often the sky is very pure and dark between sheets or strips of it. It continues luminous as long as it is under observation, which may be for a considerable part of an hour. It is possible that the luminous nights mentioned, where no streaky haze was seen, were due to a thin uniform sheeting of the luminous haze all over the sky.

To make this paper more complete I have written to Dr. W. J. Humphreys for information as to the name and nature of this haze shown on one of my day photographs. He has kindly supplied me with the following:

The streaky haze to which you refer is the cirro-stratus cloud. Near the edge, where it is thin, it might better be called cirrus.

There is no sharp division between cirrus and cirro-stratus. The thin fibrous cirrus often gradually thickens into a more or less continuous cloud veil, or sheet, in which form it is called cirro-stratus.

Its average altitude in middle latitudes is 8 to 10 kilometers. In higher latitudes its altitude is less, say 6 to 8 kilometers; and in equatorial regions roughly 10 to 12 kilometers.

It nearly if not quite always consists of snow crystals, as might be inferred from its altitude and consequent low temperatures, and as is known from the halos often seen in it.

I am also indebted to Professor Eric R. Miller, of the Weather Bureau at Madison, Wisconsin, for valuable data on the frequency of cirrus cloud in Wisconsin. Professor Miller says:

You will learn from the data sent you that there is no part of the year when cirro-stratus is absent; that it is fairly evenly distributed throughout the year.

This information is important as it shows that if the cirro-stratus were naturally self-luminous we should have luminous haze



more frequently at night. If there is no error in my identification of this form of cloud with the luminous haze, it would seem that the material must be frequently present, but that the cause of its luminosity is much less frequent.



FIG. 1. Photograph (August 19, 1917) believed to show the day appearance of the luminous night haze.

The accompanying photograph shows the streaky haze (forming the background for the cumulus clouds) to which Dr. Humphreys refers in his letter and which the present writer believes to be of a similar nature to the haze that sometimes is luminous at night. That shown in the photograph would doubtless be so dense as to blot out the stars at night. Unless, therefore, the haze were much thinner at night it could not be the same. I have seen in the day time a thin gauzy streaky haze, sometimes in large sheets, at the time that the regular denser cirro-stratus clouds were present. These would more readily represent what I refer to as luminous night haze. This I infer is still some form of the cirrus cloud. It

is very important that no mistake be made in the identification and I therefore would call attention to the objection to the denser form of cirro-stratus. This photograph, therefore, represents a denser condition of that cloud and would probably obliterate the stars at night.

In the previous paper (mentioned before) there is a suggestion that the probable passage of the earth through the tail of Halley's comet had something to do with the luminous condition of this haze, because it made its appearance very soon after that event. With the later information there is now no need to call upon the comet for an explanation of the phenomenon.

Following is given a continuation of my records of luminous haze. The times are Central Standard Time, which is 6<sup>h</sup> 0<sup>m</sup> slow of Greenwich mean time.

1911, June 17. Traces of it were suspected before moonrise, but not certain.

Aug. 28, 10<sup>h</sup> 15<sup>m</sup>. Masses of it were extending over the bowl of the Great Dipper. They were irregular and very extended to the right and left of the Dipper. The motion was slow, to the right horizontally. At 10<sup>h</sup> 35<sup>m</sup> it extended the full length of the Dipper and 15° to the right and 10° to the left of it; visible for some time and feebly luminous; steady in its light. At 14<sup>h</sup> 35<sup>m</sup> there was a long, rather bright luminous strip 4° wide extending along the bowl and handle of the Dipper; horizontal and quite bright. This was perhaps auroral. A few minutes later it had gone. No other signs of aurora.

Sept. 15, 9<sup>h</sup> 15<sup>m</sup>. Bright auroral streamers from below the horizon, but no arch. In various parts of the sky there were broad streaks and areas of luminous haze. Several very long, broad strips through the Dipper extending east and west. At 9<sup>h</sup> 25<sup>m</sup> there were thin sheets of it all over the sky, one passing over Brooks' comet which I was photographing, and another one parallel to the first 5° north of it. They extended east and west and were drifting northerly. At 9<sup>h</sup> 55<sup>m</sup> there were great streams and areas of it with dark spaces between. There was a little auroral light low in the north. At 10<sup>h</sup> 10<sup>m</sup> the two long masses of haze had drifted north. There were masses of it all over the sky, specially to the south.



Possibly there was also a slight auroral light, but it was mostly luminous haze. This was the most striking display of luminous haze I have seen. In the intervening spaces the sky was pure and dark. The aurora seemed dead at moonrise, when I stopped the exposure on the comet.

Sept. 16, 8<sup>h</sup> 30<sup>m</sup>. The sky in the southeast was luminous nearly as high as Gamma Pegasi, like approaching moon rise. There was no streakiness in the sky, but I think there was uniform luminosity. The sky was not like that of the night before. No aurora at any time.

Sept. 22, 10<sup>h</sup> 0<sup>m</sup>. There were great broad and extended masses of luminous haze over the northwest with clear, dark spaces between. Great areas of it were also present south of the zenith. No aurora.

1915, July 2. No aurora, but the night was uniformly luminous.

July 12, 11<sup>h</sup> 30<sup>m</sup>. No aurora. Luminous haze for 10° below Polaris to Gamma Ursæ Majoris. A feeble sheeting of it extended to the north horizon; its upper edge was quite definite. Above it the sky was dark. No aurora. This haze seemed to be confined to the region described. The other parts of the sky were free from it. At 11<sup>h</sup> 50<sup>m</sup> the luminous haze had drifted to the right and toward the horizon. It was then horizontal and about 20° below Polaris. Above it the sky was dark, while below it was as bright as the Milky Way to the right of it. At 12<sup>h</sup> 25<sup>m</sup> there seemed to be more of this, especially to the left of and below Jupiter. There was no aurora. The sky was not very pure. 13<sup>h</sup> 0<sup>m</sup>: In the east, all about the stars in Aries was a large luminous region almost as bright as the Milky Way; very large, like a great diffused cloud. There were no fluctuations in its light. At 13<sup>h</sup> 30<sup>m</sup> this haze was about, above and to the right of the Pleiades. It was as bright as the Milky Way. It was large and almost like dimly luminous clouds. There seemed to be a considerable amount of it near the Great Dipper and to the right of the dipper under the pole.

1916, Feb. 2, 14<sup>h</sup> 20<sup>m</sup>. No aurora, but the sky very luminous—a luminous night. The brightness increased near the horizon.

Aug. 6, 13<sup>h</sup> 30<sup>m</sup>. There was a region of luminous haze under the pole which seemed to be densest 5° above and 5° to the right

of Alpha Ursæ Majoris. There did not seem to be any evidence of ordinary aurora, but this must have been auroral. It looked as if a feeble moonlight were shining on large hazy clouds.

Dec. 4, 15<sup>h</sup> 50<sup>m</sup>. Horizontal strips of luminous haze parallel with the horizon under Cassiopeia in the northwest. Sky whitish everywhere, but no definite aurora. 16<sup>h</sup> 10<sup>m</sup>: Like dim dawn all under Cassiopeia. It consisted of sheets and strips of thin haze, like hazy clouds illuminated by a quarter moon—very noticeable. This was drifting toward the northeast. At 16<sup>h</sup> 57<sup>m</sup> the upper definite edge of this haze passed just below the Pleiades. It was 5° below and extended 20° to the right of Cassiopeia to under the Hyades. At 17<sup>h</sup> 10<sup>m</sup> it was nearing the northwest horizon. This was the best specimen of luminous haze in many years.

Dec. 21, 8<sup>h</sup> 40<sup>m</sup>. There seemed to be a long horizontal strip of luminous haze 3°–4° wide passing through Zeta Ursæ Majoris. No regular aurora. 9<sup>h</sup> 25<sup>m</sup>: A considerable amount of broad luminous haze west of the previous strip.

1917, Aug: 10, 9<sup>h</sup> 18<sup>m</sup>. Large faint auroral streamers from the north horizon. 9<sup>h</sup> 34<sup>m</sup>: Several slender auroral streamers. 10<sup>h</sup> 50<sup>m</sup>: Large areas of luminous haze in the east and near Beta Ursæ Minoris. 10<sup>h</sup> 57<sup>m</sup>: From the east horizon up to Alpha Arietis was a great sheet of faintly luminous haze slanting upward at the south end. A large area of luminous haze through Beta Ursæ Minoris to the north horizon, several degrees wide. Feeble luminous haze in high east sky. There were dark areas of pure sky free from luminous haze. Another feeble luminosity in the low north. There were no auroral streamers. By 11<sup>h</sup> 20<sup>m</sup> the luminous haze had drifted to the east of Polaris. Large areas of it all over the sky. It could be seen though the moon was up. (Moon last quarter August 9.) This luminous condition was not due to moonlight. It was the regular luminous haze seen in previous years.

Aug. 15, 8<sup>h</sup> 50<sup>m</sup>. Some masses of luminous haze. A great V-shaped portion with one broad leg through the Square of Pegasus, and the other 10° south of Altair. They met near the horizon south of the square of Pegasus. These were perhaps "left overs" from the previous night's aurora, but there was no trace of aurora to-night. At 9<sup>h</sup> 55<sup>m</sup> the great stream of luminous haze lay



between Cassiopeia and Perseus, and was  $10^\circ$  under Polaris. It was  $10^\circ$  broad. Another ran through Alpha Cassiopeia and met the first near the southwest horizon. There were several streams of it from the intersection running upwards. These were as bright as the Milky Way near Alpha Cygni. The sky between was very clear. At  $11^h 10^m$  the luminous band in the northeast was between Alpha Persei and Capella. It was bright—brighter than any part of the Milky Way. There were many less bright strips to the east of the zenith. No aurora. (On August 14 there was a large aurora.)  $12^h 45^m$ : All the sky except overhead was unequally covered with luminous haze. In the east and northeast there were great long streaks of it,  $10^\circ$  or more wide. Also in the south. This was as bright as the Milky Way. It was very strikingly dark where the sky showed between.

Aug. 16,  $10^h 0^m$ . A very feeble glow low in the north, like a very faint aurora. No luminous haze to-night so far. At  $10^h 20^m$  there was a broad strip of luminous haze running from Altair east by north through a point in  $\alpha 22^h 20^m$ ,  $\delta 0^\circ$ . It was  $10^\circ$  broad and quite noticeable when looked at for a few minutes.  $11^h 40^m$ : Strong aurora with streamers and very low arch.  $12^h 20^m$ : Aurora not very active, but strong glow. At  $12^h 50^m$  there was only a strong auroral glow.

Aug. 18,  $10^h 55^m$ . No aurora, but sky luminous; perhaps some luminous haze in the south.  $15^h 52^m$ : East edge of a broad sheet of luminous haze passing over Alpha Arietis.  $15^h 58^m$ : The south edge of this was passing the Pleiades.  $16^h 2^m$ : East edge over Jupiter.  $16^h 23^m$ : It was now massing up into little patchy clouds. There was a great amount of it all over the sky. It was pale white. There were some dark clouds lower in the east against the dawn.

Aug. 19,  $10^h 15^m$  to  $10^h 45^m$ . Looked carefully for luminous haze, but none was visible. Sky very thickish; Milky Way very dull.  $15^h 15^m$ : Sky very dull. No luminous haze or clouds.  $15^h 33^m$ : No luminous haze. Sky thickish; specially thick over Jupiter and the Pleiades. Some misty haze—not luminous. Some zodiacal light at  $15^h 42^m$ . Some feeble luminous haze above Jupiter and the Pleiades. A great deal of dark haze; a long mass of it was probably feebly luminous in Cassiopeia and evidences of it at a

number of other places. 15<sup>h</sup> 50<sup>m</sup>: There were streaks and masses of haze feebly luminous near the Pleiades; some strong strips and great sheets of it all over the south. These were not self-luminous, but were all brought into view, evidently, by reflecting the first feeble dawn. They were, however, beyond question the same stuff that had recently appeared luminous at night.

Aug. 24, 12<sup>h</sup> 50<sup>m</sup>. No aurora. There were horizontal strips of luminous haze through the upper part of the Great Dipper with a clear space below them, with more luminous haze lower down. Great long masses through Hercules with clear space below; then more of it to the northwest horizon. 14<sup>h</sup> 30<sup>m</sup>: A rather strong strip of luminous haze just above the handle of the Great Dipper in the north. There was also a horizontal strip across Vega with a clear space below it. No aurora. The sky where there was no luminous haze was very clear. 15<sup>h</sup> 50<sup>m</sup>: No aurora.

Dec. 21, 14<sup>h</sup> 10<sup>m</sup>. No aurora. 14<sup>h</sup> 44<sup>m</sup>: No aurora. I noticed a little later what appeared to be a strong zodiacal light passing through Spica in the southeast at 14<sup>h</sup> 57<sup>m</sup>; this proved to be an extended luminous haze. At 15<sup>h</sup> 30<sup>m</sup> the upper part of it passed through Alpha and Epsilon and Beta Crateris and Gamma Hydræ. The upper edge was rather definite. The whole mass extended from the east horizon to beyond Crater. The motion of all this was to the southeast. The sky was dark below Spica to the edge of the haze. There was much very diffused light extending above Spica for 20° or more. 16<sup>h</sup> 25<sup>m</sup>: A diffused luminosity like dawn all along the southeast horizon and upwards where the luminous haze had drifted, no aurora. 17<sup>h</sup> 5<sup>m</sup>: There was a dawn-like light all about Alpha and Beta Libræ. 17<sup>h</sup> 30<sup>m</sup>: No aurora. The zodiacal light was very strong. No luminous haze anywhere. This exhibition of luminous haze was very noticeable. At first it was taken for the zodiacal light and thought to be unusually bright, but it drifted to the southeast and disappeared before the zodiacal light manifested itself. The light of the luminous haze was soft, like that of the zodiacal light, but stronger, and there was a rather definite edge to it. There was no evidence of aurora at any time, though looked for carefully. There was no other luminous haze. This was extended from the east horizon to above Spica at first, to the southeast, almost horizontally, beyond Alpha Crateris.



1918, Sept. 2, 9<sup>h</sup> 17<sup>m</sup>. A strip of luminous haze 4° wide ran diagonally across the Square of Pegasus from Beta and beyond Gamma Pegasi. 9<sup>h</sup> 24<sup>m</sup>: A similar mass ran from the Dolphin to Alpha Pegasi. No aurora. 10<sup>h</sup> 35<sup>m</sup>: No aurora. A region of luminous haze over the handle of the Dipper in the northwest. There seems to have been a great deal of it on this night. 11<sup>h</sup> 25<sup>m</sup>: Luminous haze all over the north; a great sheet of it with clear spaces here and there. No aurora on this night, but a great deal of luminous haze.

Sept. 8, 9<sup>h</sup> 30<sup>m</sup>. At this time there was a great deal of luminous haze all over the northwest, as high as 4° or 5° above the Dipper. It was quite strong. A long strip of it 5° wide extended from above Gamma Pegasi to Aries. Though there was no aurora on this night, there was a great deal of luminous haze.

Oct. 5, 12<sup>h</sup> 30<sup>m</sup>. The sky was luminous. There was no aurora. It was about as bright as if a quarter moon were, say, in the west. It was uniform and was apparently not the regular light of luminous haze. Could readily read my watch by this light. The Milky Way was very dim with it.

I have gone to some length in the descriptions and locations of the masses, etc., of luminous haze because so little is known of the origin of its light that it is believed the observations may sometime be more important than they appear to be at present.

The following tabular scheme will roughly show the frequency of luminous haze as indicated by my records. The numbers indicate the number of nights on which it was seen during the month.

	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.
January.....	1	..	..	..	..	..	..	..	..
February.....	1	1	..	..	..	..	1	..	..
March.....	1	1	..	..	..	..	..	..	..
April.....	1	..	..	..	..	..	..	..	..
May.....	1	..	..	..	..	..	..	..	..
June.....	3	1	..	..	..	..	..	..	..
July.....	..	..	..	..	..	2	..	..	..
August.....	..	1	..	..	..	2	..	..	..
September.....	2	3	..	..	..	..	1	6	..
October.....	5	..	..	..	..	..	..	..	2
November.....	2	..	..	..	..	..	..	..	1
December.....	..	..	..	..	..	..	2	1	..

As will be seen from the above table, January, April and May

seem to be the only months in which the haze was not observed. It was not seen during the years 1912, 1913 and 1914. The greatest amount of it was recorded in October, 1910, and August, 1917. The first half of 1910 must not be considered because the haze was not noticed until June and as it was not looked for it may have been present.

A strict comparison cannot be safely made between the frequency of luminous haze and that of the aurora by noting the relative number of nights on which they were visible, because often auroras appear in the presence of bright moonlight in which the luminous haze would not be visible. Nevertheless, it may be important to have even a rough comparison. For this purpose, therefore, I have collected the following dates on which auroras were seen, which covers the entire period over which the luminous haze has been under observation by me. They are from my own records of the aurora which I have kept here for over twenty years. The dates alone are given. A [?] means uncertainty as to whether the observation was of a real aurora. Some of the auroras are of very short duration and hence the apparition of an aurora on the date of an observation of luminous haze may not have been coincident with the latter by many hours. The details of the above auroral records will be published later as a continuation of the two lists already printed in the *Astrophysical Journal*, Vol. 16, p. 135, 1902 and Vol. 31, p. 208, 1910.

1910, May	3	Oct.	2[?]	Mar.	20[?]
"	18	"	7	"	24
"	24	"	27	"	30
"	27	"	30	Apr.	8
"	30	Nov.	1	"	16
June	19	"	29	May	31
July	4	1911, Feb.	20	June	4
Aug.	9	"	21	July	17
"	10	"	22	Aug.	2
Sept.	6	"	23[?]	"	22
"	10	"	24	"	23
"	27	"	28	"	24
"	30	Mar.	19	"	28



Sept.	15	July	1	Aug.	22
"	19	"	5	"	23
"	21	"	8	"	26
Oct.	10	"	11	"	27[?]
1912, Jan.	12	Aug.	6	"	28
May	13	"	17	Sept.	2
June	7	"	19	"	4
"	8	Sept.	9[?]	"	7
Nov.	14	"	16	"	16
"	15	"	21	"	22
1913, Feb.	13	"	28	"	30
Mar.	13	"	29	Oct.	1
Aug.	29[?]	Oct.	1[?]	"	5
Sept.	22	"	14	"	6
1914, Apr.	18	Nov.	1	"	7
July	24	"	5	Nov.	20
"	29	"	8	Dec.	27
Aug.	28	"	11	"	28
Sept.	15	"	16	1917, Jan.	7
"	17	Dec.	7	"	25[?]
"	22	1916, Jan.	10	Feb.	17
"	25[?]	"	22	"	19
"	28	Mar.	8	"	27
Oct.	20	"	10	Mar.	19[?]
"	27	"	16	"	20
Nov.	15	"	29	May	1
"	16	Apr.	1	"	2
1915, Apr.	2[?]	"	5	June	13
"	7	"	27	July	1
"	16	May	22	"	12
"	17	"	30	"	28
"	25	June	19	Aug.	8
May	16	"	24	"	9
June	16	July	5	"	10
"	17	"	8	"	14
"	21	"	23	"	16
"	24	Aug.	19	"	25

Oct.	13	Apr.	17	Oct.	3
"	24	"	29	"	6
"	27	July	30	"	8
Nov.	18	Aug.	2	"	9
Dec.	8	"	5	"	15
"	14	"	24	"	16
1918, Jan.	13	"	25	Nov.	10
Feb.	12	"	26	"	11
Mar.	3	"	28[?]	"	12
"	7	"	31	"	13
"	14	Sept.	7	"	24
"	15	"	12	"	29
Apr.	3	"	15	"	30
"	4	"	26	Dec.	3
"	5	"	28	"	7
"	6	"	29	"	8
"	8	"	30	"	19[?]
"	10	Oct.	2[?] 1919, Jan.		3

YERKES OBSERVATORY,  
 WILLIAMS BAY, WISCONSIN,  
 April 4, 1919.



## GRAPHICAL REPRESENTATION OF FUNCTIONS OF THE NTH DEGREE.

By FRANCIS E. NIPHER.

(Read April 26, 1919.)

It has been generally assumed that any algebraic symbol  $y$ , the exponent of which is unity, can only be properly represented graphically by a line. When the exponent is 2, the quantity  $y^2$  has been assumed to represent a rectangular area, the four sides of which each have a length  $y$ . If the exponent is 3, the proper geometrical representation was said to be a rectangular volume, having six faces whose areas were  $y^2$ . If the exponent were 4, the philosophic mind began to speculate on the nature of space having four dimensions. No definite solution of this problem having been reached, it has apparently been considered impracticable to consider the properties of space having six or eight or ten dimensions.

During this period of uncertainty it has been known to students of elementary algebra that

$$\frac{1}{y^{1/3}} = \frac{y^{1/3}}{y^{2/3}} = \frac{y^{2/3}}{y} = \frac{y}{y^{4/3}} = \frac{y^{4/3}}{y^{5/3}} = \frac{y^{5/3}}{y^2}, \text{ etc.}$$

It has also been known that similar right triangles have sides whose lengths are directly proportional. This is illustrated in Fig. 1 where an arbitrarily chosen length is adopted as a unit of length. Its length in terms of the centimeter is unknown. Another length is similarly chosen to represent  $y^{\frac{1}{3}}$ , where  $y$  is to be given a numerical value in terms of the chosen unit, but this value need not be determined.

These lengths having been laid off upon rectangular axes, the lengths  $y^{\frac{2}{3}}$ ,  $y$ ,  $y^{\frac{4}{3}}$ ,  $y^{\frac{5}{3}}$ ,  $y^2$ , etc., can be laid off upon the two axes by a well-known geometrical method. By means of three parallel rulers, two of which are linked to the third in the usual manner, the lengths unity and  $y$  may be first adopted and laid off on both axes, and the

lengths  $y^{\frac{1}{2}}$  and  $y^{\frac{1}{3}}$  can then be laid off. By means of two rulers in parallel, the length  $y^{\frac{1}{3}}$  can similarly be laid off upon both axes. The lengths  $y^{\frac{1}{2}}$ ,  $y^{\frac{2}{3}}$ , etc., can then be similarly laid off upon the two axes. Since

$$\frac{y}{1} = \frac{xy}{x} = \frac{x^2y}{x^2} = \frac{x^3y}{x^3}, \text{ etc.},$$

it is evident that any value  $x^n y^m$  can be laid off by purely geometrical methods. The exponents  $n$  and  $m$  may be in decimal form and may range in numerical value from 0.1 to 100 if the experimenter so desires, and all of these values may be represented by lines.

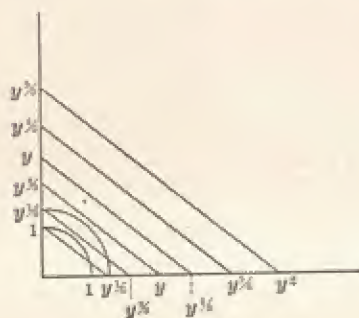


FIG. 1.

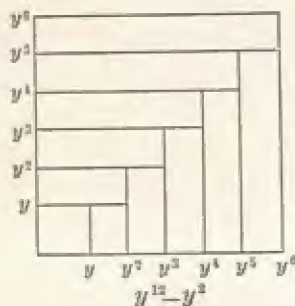


FIG. 2.

In Fig. 2 we have a system of squares constructed on lines determined by the method described above. The areas of the squares vary from  $y^2$  to  $y^{12}$ . The difference between the areas of the outer and the inner squares is  $y^{12} - y^2$ .

This value is divisible by  $y^2 - y$ . The value so determined is

$$\frac{y^{12} - y^2}{y^2 - y} = y^{10} + y^9 + y^8 + y^7 + y^6 + y^5 + y^4 + y^3 + y^2 + y.$$

Multiplying both members of this equation by  $y^2 - y$ , it may be put into the form

$$\begin{aligned} y^{12} - y^2 &= y^6(y^6 - y^5) + y^5(y^6 - y^5) \\ &+ y^5(y^5 - y^4) + y^4(y^5 - y^4) \\ &+ y^4(y^4 - y^3) + y^3(y^4 - y^3) \end{aligned}$$



$$\begin{aligned}
 &+ y^3(y^3 - y^2) + y^2(y^3 - y^2) \\
 &+ y^2(y^2 - y) + y(y^2 - y). \quad (1) \\
 &y^{12} - y^2.
 \end{aligned}$$

The first two terms of the second member of this equation represent the area of the two outer rectangles between the two squares having areas  $y^{12}$  and  $y^{10}$ . These rectangles each have a width  $y^6$

$- y^5$ , and their combined length is  $y^6 + y^5$ . The remaining terms represent the remaining strip areas, between the squares  $y^{12}$  and  $y^2$ ,

$$y^{18} - y^2.$$

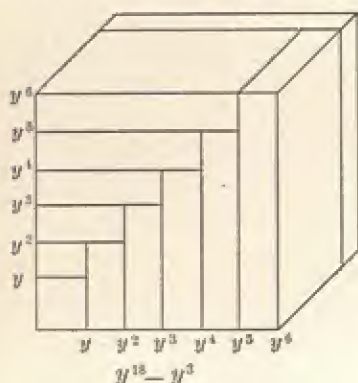


FIG. 3.

Fig. 3 represents a cube, the volume within the outer surface of which is  $y^{18}$ . In the lower left-hand corner is a cube having a volume  $y^3$ . Between these cubes are fifteen blocks filling the space between the two cubes. If this cube

were to be placed upon the area forming Fig. 2, each block which stands on edge would cover a rectangular area shown in Fig. 2. Dividing the difference between the volumes by  $y^2 - y$  as in the former case we have

$$\frac{y^{18} - y^3}{y^2 - y} = y^{16} + y^{15} + \dots y^2.$$

Multiplying by  $y^2 - y$  as before the resulting terms may be written

$$\begin{aligned}
 y^{18} - y^3 &= y^6 y^6 (y^6 - y^5) + y^6 y^5 (y^6 - y^5) + y^5 y^5 (y^6 - y^5) \\
 &+ y^5 y^5 (y^5 - y^4) + y^5 y^4 (y^5 - y^4) + y^4 y^4 (y^5 - y^4) \\
 &+ y^4 y^4 (y^4 - y^3) + y^4 y^3 (y^4 - y^3) + y^3 y^3 (y^4 - y^3) \\
 &+ y^3 y^3 (y^3 - y^2) + y^3 y^2 (y^3 - y^2) + y^2 y^2 (y^3 - y^2) \\
 &+ y^2 y^2 (y^2 - y) + y^2 y (y^2 - y) + y y (y^2 - y). \quad (2)
 \end{aligned}$$

The first term in the second member of the equation represents the volume of the block at the rear of the cube  $y^{18}$ . Its dimensions are  $y^6$ ,  $y^6$  and  $y^6 - y^3$ . The second term represents the volume of the block on the right side of the cube  $y^{18}$ . The dimensions are  $y^6$ ,  $y^3$  and  $y^6 - y^3$ . The third term gives the volume of the block covering the upper face of the cube  $y^{15}$ . The volume of the three blocks is  $y^{18} - y^{15}$ . This will be the result obtained by adding these three terms together. Each of these three terms may be given a very different interpretation. They are each a difference between two quantities. They are therefore each the difference between the cubes of two other quantities,

$$y^6 y^6 (y^6 - y^3) = y^{18} - y^{17}.$$

This result shows that the volume of the block forming the back of the cube whose volume is  $y^{18}$  is also equal to the volume of three blocks between the cubes  $y^{18}$  and  $y^{17}$ . We may therefore write the value of this term as follows:

$$\begin{aligned} y^{18} - y^{17} &= y^6 y^6 (y^6 - y^{15/2}) \\ &\quad + y^6 y^{15/2} (y^6 - y^{15/2}) \\ &\quad + y^{15/2} y^{15/2} (y^6 - y^{15/2}). \end{aligned}$$

In this case the inner cube would have edges whose length is  $y^{15/2}$ . This length can be laid off on the three axes by purely geometrical means, as has been pointed out in the present paper.

The second term of Eq. (2), which represents the volume of the block on the right side of Fig. 2, may also represent the volume of three blocks between cubes  $y^{17}$  and  $y^{16}$ . The third term representing the block at the top of the large cube may also represent the volume  $y^{16} - y^{15}$ . These nine blocks would fill the volume occupied by the three outer blocks of Fig. 3.

The thickness of the three shells filling the volume  $y^{18} - y^{15}$  is  $(y^6 - y^{15/2}) + (y^{15/2} - y^{15/2}) + (y^{15/2} - y^3)$ . Of course, all of the terms of Eq. (2) can be similarly treated, and the operation may be repeated on the terms resulting.

Equation (2) may also represent the difference between the areas of two squares,  $y^{18}$  and  $y^9$ , having sides whose lengths are  $y^9$  and  $y^{3/2}$ . As the second member has an odd number of terms, the



final term is resolved into two terms by considering it to be the difference between two squares having areas  $y^4$  and  $y^2$ . The equation may therefore be written

$$\begin{aligned} y^{18} - y^2 = & y^0(y^0 - y^8) + y^6(y^0 - y^8) \\ & + y^8(y^8 - y^7) + y^7(y^8 - y^7) \\ & + y^7(y^7 - y^6) + y^6(y^7 - y^6) \\ & + y^6(y^6 - y^5) + y^5(y^6 - y^5) \\ & + y^5(y^5 - y^4) + y^4(y^5 - y^4) \\ & + y^4(y^4 - y^3) + y^3(y^4 - y^3) \\ & + y^3(y^3 - y^2) + y^2(y^3 - y^2) \\ & + y^2(y^2 - y^{\frac{3}{2}}) + y^{\frac{3}{2}}(y^2 - y^{\frac{3}{2}}). \end{aligned}$$

Equation (1) may also represent the difference between the volumes  $y^{12}$  and  $y^2$  of two cubes having edges whose lengths are  $y^4$  and  $y^{\frac{1}{2}}$ . That equation may be written

$$\begin{aligned} y^{12} - y^2 = & y^4y^4(y^4 - y^2) + y^4y^3(y^4 - y^2) + y^3y^3(y^4 - y^2) \\ & + y^3y^3(y^3 - y^2) + y^3y^2(y^3 - y^2) + y^2y^2(y^3 - y^2) \\ & + y^2y^2(y^2 - y) + y^2y(y^2 - y) + y y(y^2 - y) \\ & + y y(y - y^{\frac{3}{2}}) + y y^{\frac{3}{2}}(y - y^{\frac{3}{2}}) + y^{\frac{3}{2}}y^{\frac{3}{2}}(y - y^{\frac{3}{2}}). \end{aligned}$$

Here the final term  $(y^3 - y^2)$  of Eq. (1) has been considered as the difference between the volumes of two cubes having edges the lengths of which are  $y$  and  $y^{\frac{3}{2}}$ .

The last equation may be written

$$y^{12} - y^2 = [(y^4)^3 - (y^2)^3] + [(y^3)^2 - (y^2)^2] + [(y^2)^2 - y^2] + [y^3 - y^2].$$

Of course, this discussion does not in any way modify the physical or geometrical meaning of the units linear foot, square foot or cubic foot. A contractor who should order of dealers in such material 64 feet of garden-hose, 64 feet of sheet tin and 64 feet of sand or gravel, would not learn that any of his orders had been misunderstood. Possibly they might not be understood if he were to order 2<sup>nd</sup> feet of each of these materials.

# THE CROCKER ECLIPSE EXPEDITION FROM THE LICK OBSERVATORY, JUNE 8, 1918.

## SOME ECLIPSE PROBLEMS.

BY W. W. CAMPBELL.

(*Read April 25, 1919.*)

Eclipse observers have always before them two principal questions:

What is the solar corona?

Why does the sun have a corona?

It must be confessed that the best answers at present available are far from satisfactory and complete. We have established many important facts, especially as to the nature of the corona, but these are more or less isolated facts, with suggestions here and there as to the relations of the facts to each other. That the progress made has not been greater is due to the tantalizingly short time available for observation. In the past twenty-one years I have had a total of twelve minutes in which to secure observations of the corona, and during four of those minutes—in Spain—the observations were made through thin clouds.

It is not a narrow interest which directs our efforts. The corona is a part of the sun, and we can never claim to know what the sun is until we understand all parts of it, including the corona, and the reasons for the corona's existence. The sunspots, the faculæ, the flocculi, and the prominences are undoubted evidence of great activity of movement in the sun's outer strata. It seems not too much to hope that a thorough understanding of the corona will contribute greatly to an understanding of the sun's circulatory system.

Again, it is not alone the more thorough understanding of our own sun which supplies the motive for eclipse study. Is there a corona around every sun? There may be; solar coronas may be plentiful throughout the universe, but we do not know. A complete understanding of our own star is certainly a pressing duty to the



investigator who looks toward the understanding of the stars in general.

#### THE FORM OF THE CORONA.

Near the end of last century eclipse observers recognized that the outline of the corona is a function of the sunspot phase. Our first slide (No. 1) illustrates well this general relationship. The coronas here shown, proceeding from right to left, are, first, that of 1889, at sunspot minimum; second, the corona of 1893, at sunspot maximum; third, the minimum corona of 1900; and fourth, the maximum corona of 1905. In all of these the sun's equator is nearly vertical with reference to the slide, and the sun's rotation axis is nearly horizontal. The phenomena in question are illustrated in a more interesting manner by the second and third slides of the corona on a larger scale. The circular corona (No. 2) is that of the 1893 eclipse, and the greatly elongated one (No. 3) is of the year 1900.

It is perhaps natural to expect that the polar streamers of the corona should be more extensive at times of great solar activity, as indicated by the maximum phase of spottedness, but that the equatorial streamers should be the longer at sunspot minimum would scarcely have been predicted.

It cannot be said, however, that the outline form of the corona is accurately predictable from the known phase of the sunspot-cycle. We photographed the corona (slide No. 4) with cameras of focal lengths varying from four feet to forty feet on June 8, 1918, at Goldendale, Washington. The spot phase was but a few months past the maximum, and we expected the corona to be essentially circular in outline. Our predictions were not fulfilled so satisfactorily as we had expected. Slide No. 5, an exposure of four seconds with a camera whose focal length was four feet, shows streamers extending out to approximately three solar diameters to the right and to the left, that is, to the west and east of the sun, whereas the streamers to the north and south (above and below) are very much shorter. The sixth slide is one obtained with the forty-foot camera, exposure four seconds; the departure from circularity of outline is very marked even for the inner corona. Does the circular type of

corona prevail only during a short period of time at a well-defined phase of maximum spottedness, or is the relation of outline form to spot phase not very definite? Future eclipses should try to determine the relationship more precisely than we can be said to know it at present. The equipment needed for this work is inexpensive. Cameras of moderate length, say from four to seven feet, are abundantly powerful.

There has been no satisfactory hypothesis proposed to account for the undoubted relationship of coronal form and sunspot phase.

#### RELATIONSHIP OF CORONAL STREAMERS TO OTHER SOLAR PHENOMENA.

The relations of coronal structure to other phenomena of the sun, such as the prominences, sunspots, and faculae, are subjects of inquiry with every corona recorded. Our slide No. 7, the eclipse of 1898 in India, shows clearly, and I think for the first time, the hooded forms of coronal structures which encircle some of the prominences. The following eclipse, that of 1900 in Georgia, did not show this feature, unless perhaps very mildly in the case of one prominence. The larger prominences in 1900 were certainly unattended by these hooded coronal forms. Later eclipses showed the occasional presence of this phenomenon, but not strongly, until we come to the eclipse of last year, when it was very marked indeed. Slide No. 8 is an exposure of one second on Seed thirty plates obtained with the camera of forty feet focus. Nearly all of the larger prominences and some of the smaller ones are enclosed by strong and well-defined hoods. There can be no doubt, I think, that the prominences and the curved streamers encircling them possess some kind of intimate relationship. The greater part of the inner corona recorded by this photograph consists of these curving streamers.

Slide No. 9 is a four-second exposure made with the same instrument. The most of the strong coronal structure here shown appears likewise to be under the control of, or to have intimate relationship of some kind with, the prominences which seem to lie at centers of controlling influence. Nearly all of the structure to the right of the sun is divided into three main compartments, each with a prominence at the central point of contact with the sun's limb.



Slide No. 10 is an enlargement showing one of these sections on a still greater scale. The division of this part of the corona into three sections by the two intervening vacancies is clearly marked.

The corona of 1893, at sunspot maximum, slide No. 11, does not show this interesting phenomenon to have been present. Why it should have been observed so much more conspicuously in 1918 than at other time remains unanswered.

My colleague, Dr. Moore, had attempted to correlate the main features of last year's corona with the prominences then visible and with the positions of sunspots and faculae as they existed on the day of the eclipse. The Mount Wilson Observatory has generously lent its solar photographs secured on that day, and on several days preceding and following, for this purpose, and we gladly make due acknowledgment of our indebtedness. Lantern slide No. 12 illustrates the position of coronal structure, prominences, sunspots, and faculae, at the instant of the 1918 eclipse, as measured roughly, or estimated, from the Mount Wilson observations obtained on the several consecutive days. The features on the front side and near the limb of the solar sphere are illustrated on the central circle of the slide, and the features thought to be on the rear side of the sun are set down on the right and left wings of the slide. The well-defined symbols represent the spots and the poorly-defined markings the faculae. It cannot be said from this sketch that the prominences were situated above visible sunspots or faculae. The hooded coronal forms therefore appear not to have been controlled from centers of disturbance coinciding with spots or faculae. The vacancy in the coronal structure directly to the right of the sun is approximately in a plane passing through the observer, the center of the sun, and the group of spots and faculae visible in the sketch to the right of the center, but, in view of the positions of the two principal prominences on the right edge of the sun, occupying the central points of their hooded structures, we seem not justified in looking further at present for a relationship between the vacancy in the coronal structure and the group of spots and faculae. This group is really more than  $40^\circ$  from the sun's east limb.

Professor Perrine's coronal photographs of 1901, in Sumatra, recorded what he called a "disturbed" volume of the corona. It is

shown in slide No. 13. Examining the photographs of the sun obtained on and near the day of the eclipse, he found that a prominent sunspot, in fact the only conspicuous sunspot known to be on the sun at that time, was situated very close to the sun's limb, and immediately under the center of the disturbance in the corona. The same slide shows a small prominence to the left of the sun—near the lower left edge of the slide—with a faint hooded enclosure.

This subject of relations between coronal structure and other solar phenomena is a very interesting and important one for eclipse observers of the future to hold in mind.

#### THE FORMS OF CORONAL STREAMERS.

The force which carries materials into the coronal region may be volcanic, as Schaeberle and others have suggested, or it may be chiefly radiation pressure, or a combination of these, or indeed a force of quite unknown nature. The arrangement of the coronal materials in the well-defined streamers may be a result of the sun's magnetic properties, as Bigelow and others have thought, but if so the principal features of the 1918 corona, especially to the east and west of the sun, would require that merely local magnetic fields be in control. The polar streamers certainly are very suggestive of control by the sun's general magnetic forces, but this influence does not seem to be the prevailing one in the remaining coronal structure.

#### MOTION WITHIN THE CORONA.

Inasmuch as the corona of one eclipse is different in every detail from that of the succeeding eclipse, we cannot doubt the existence of motion and change within the corona. An interesting question is, how rapidly do these changes occur? Can they be detected from a comparison of coronal photographs of the same eclipse, obtained at two or more stations distributed along the path of totality? This is a problem which eclipse observers have held in mind during several decades. The eclipse of 1905 seemed especially promising for an attack upon this problem. Crocker expeditions from the Lick Observatory were located in Labrador, in Spain, and in Upper Egypt, with the principal motive the obtaining of coronal photo-



graphs separated by the considerable intervals of time, with a view to the detection of motion in coronal structure during the intervals. Clouds prevented observation in Labrador; excellent photographs were obtained through thin clouds in Spain, but the Egyptian photographs were not well-defined, owing to disturbances in the atmosphere, probably arising from the highly heated desert conditions of the middle afternoon. Slide No. 14 compares an interesting region of the corona as photographed in Spain and Egypt, with cameras of identical dimensions, focal lengths forty feet. The great prominence, it will be noticed, was sharply defined in Spain (on the left), but the definition was poor in Egypt (on the right). Many details of prominence structure changed during the interval of approximately seventy minutes, but we are not concerned especially with changes in prominences, as this is one of their well-known characteristics which may be and has been studied successfully on many days of the year at home. A comparison of the coronal structure in the region of the prominence is made difficult by the good definition in one case and the mediocre definition in the other, but there is no doubt that many changes occurred in the coronal details while the moon's shadow was passing from Spain to Egypt. Dr. Perrine and I were unable to say, however, that the motion was outward or inward, or that it was due to decrease of brightness for certain details and increase for others. Expressed differently, there were evident changes of detailed structure, but these changes were apparently haphazard rather than due to motion of illuminated materials systematically outward or inward. Nevertheless, that changes did occur in the interval is certain.

Dr. Moore has compared our 1918 coronal photographs obtained in the State of Washington with copies of those obtained by the Lowell Observatory Expedition, in Kansas, thanks to Director Slipher's courtesy. The scales are different, and the atmospheric conditions were poorer in Kansas, so that comparisons of our originals with copies of the Lowell photographs are difficult and unsatisfactory. Nevertheless, many changes in details are noted to have occurred in the interval of one half hour. Some of these seem to be the result of motion outward and others of motion inward, but we are not prepared to say that one or the other motion is the prevailing tendency.

The search for changes in coronal structure evidently remains one of the most interesting eclipse problems of the future. The photographs secured at points as widely separated in time as possible should be made with instruments of long focus, forty feet or more, and under conditions as nearly identical as practicable. Slow plates, such as Seed 23, preferably of the non-halation type, or suitably backed to avoid internal reflections, should be used, and the program of exposures at the different stations should be of identical efficiency. The utmost pains should be taken to have the plates in perfect focus and the diurnal motion accurately allowed for. The camera should be so designed that heated air within the camera itself would not detract from the definition. There remains the factor beyond control, the different states of the atmosphere at the various stations, and this is a serious factor indeed, as will be recognized by every observer who has endeavored to compare measures of sharply defined photographs with others of the same object but less definite.

Copies of the photographs obtained in 1918 by the Lick Observatory have been distributed to other institutions known to be interested in the subject, and if a comparison of these with photographs obtained at other stations should reveal definite evidence of coronal changes in the intervals we shall be very pleased indeed.

#### POLARIZED LIGHT IN THE CORONA.

A study of the polarized light in the corona has long been recognized as of great importance. Much remains to be done in this field of inquiry. The photography of the corona through double image prisms (slide No. 15) has both advantages and disadvantages. The latter arise in part from the factor of chromatic aberration when utilizing coronal rays having a great range of wavelength values. The definition under these conditions is unavoidably not all that should be desired, and some uncertainty in the quantitative results necessarily follows. The method of inclined plane glass reflectors in front of the coronal cameras, as used successfully by Dr. Perrine (slide No. 16), has its advantages. In this slide the richness of polarized light in the corona is indicated by the greater vertical dimensions of the right hand image, and the greater horizontal dimensions of the left-hand image.



A point of first importance in any method of studying the polarized light consists in making sure that the apparatus itself does not introduce polarization, and thus vitiate and render uncertain the observational data. One should be especially on his guard when using quartz and possibly other optical pieces in any way. Before definitely adopting any form or design of analyzing apparatus, laboratory tests should be made to ensure that this apparatus may be trusted not to produce its own polarization effects.

### THE SPECTRUM OF THE CORONA.

The spectrographic study of the corona at eclipses of the past two or three decades has led to tolerably definite ideas as to the quality of the coronal light. That there are shallow strata of incandescent gases overlying the photosphere and chromosphere of the sun is certain. However, the use of the term strata in this connection may be misleading. Some of the strata seem to be fairly uniform in thickness over large arcs of the sun's limb, or change their thickness very gradually in passing from one region to another, but in other cases the thickness is very irregular. Slide No. 17 is an exposure, effectively short, secured with a grating spectrograph in 1918, to record the so-called green coronal ring consisting of radiations with wave-length  $5303\text{\AA}$ . The ring is seen to be "lumpy." Similar photographs of the ring at wave-length  $4231\text{\AA}$  have shown it to be more nearly uniform in thickness. The principal condensations in the green ring are adjacent to prominences, but not in coincidence with them. In the illustration the positions of the principal prominences are indicated by the dotted line enclosures lying outside of the green ring. The positions of the  $5303$  maxima are indicated by the dotted line extending inward from the ring and bearing numbers indicating the north and south solar latitudes. The green condensations are slightly farther from the solar equator than are the adjacent prominences. If the condensations are related to the prominences, the relationship is not immediate and intimate. There is poverty of green material near the north and south poles of the sun.

The faint dark bands passing through the green condensations have been noted at earlier eclipses. The condensations are undoubt-

edly strengthened a little by the superposition of these bands of continuous light with the green ring. The origin of the continuous bands has been under discussion. It has seemed to me that the materials responsible for the green ring yield continuous radiations more abundantly than special radiations, for it must be remembered that the latter are condensed in the slender ring, whereas the faint continuous bands stretch from end to end of the spectrum. The energy represented by the green ring, and in fact by all the bright coronal rings, is exceedingly slight in comparison with the sum total of coronal radiations, and apparently represents but a small fraction of the radiations proceeding from the bright ring materials themselves. It has been suggested that the faint bands passing through the condensations in the green ring may proceed principally from prominences; and, again, that they may have had their origin in photospheric light passing through depressions in the moon's edge, owing to the exposures having begun too soon after contact II., or continued too close to contact III. I do not think the point has been well taken, for the relationship of the continuous bands to the green condensations is plainly evident, and there is no apparent reason why these condensations should be related to depressions in the moon's edge. Again, there is a considerable number of extant coronal spectrograms bearing upon the subject. Slide No. 18 is from Lockyer's photograph of 1905. The green coronal ring to the right contains a prominent condensation through which passes a strong band of continuous radiation. This band is shown on the left in the H and K calcium region of the same spectrogram. The band misses the calcium prominences very skilfully. In the same way the hydrogen images of the prominences on the same spectrogram do not show the continuous band as passing through them.

The coronal spectrograms of recent decades are essentially agreed that the continuous radiations of the bright inner corona are but feebly and inappreciably affected by Fraunhofer absorption, thus establishing, in my opinion, that the inner coronal materials are chiefly incandescent and supply us with radiations of their own, to which reflected or diffused photospheric light makes but a small addition. The spectrum of the outer corona, on the contrary, say regions lying ten or fifteen minutes, or farther, from the sun's edge,



undoubtedly contains the Fraunhofer lines. The interpretation is that the outer corona is shining, possibly in part by its own light, but chiefly by virtue of the photospheric rays falling upon the outer coronal materials. Slide No. 19 was obtained in 1918. The broad spectrum is that of the sun itself. The spectrum of the corona to the west of the sun is in the upper narrow band. The green bright line is shown on the extreme right, and the ultra-violet bright line at 3601A is very close to the extreme left end. The bright points on the lower edge of the coronal spectrum are from the prominences. The radiations in two long bright lines at H and K undoubtedly originate chiefly in the prominences, and the great length of these lines is due to the diffusion of the calcium light in its own atmosphere. The exposure was in effect too short to record the spectrum of the outer corona. No dark lines are visible. Spectrograms secured by us at earlier eclipses have recorded dark lines in the outer corona.

Trustworthy observations of this kind require an absolutely clear sky. It is dangerous to draw conclusions from spectrograms obtained through light clouds. This is illustrated by slide No. 20, copied from the coronal spectrogram secured in Sumatra in 1901. The Fraunhofer lines are shown strongly in the outer corona, *and likewise upon the dark moon!* Much of the Fraunhofer effect is undoubtedly due to the diffusion of the sun's photospheric rays by the thin clouds which covered the sky at that time.

The observed polarization effects are in harmony with the spectrographic as to the nature of the continuous coronal radiations.

#### ROTATION OF THE CORONA.

A few observers have sought to determine the rotational speed of the corona as a Doppler-Fizeau effect, by measuring the accurate wave-lengths of the green bright line to the east and to the west of the sun. If the corona is rotating with a speed approximating that of the sun's underlying surface, then the corona adjoining the east limb of the sun should be approaching us at the rate of two km. per second, and the corresponding coronal structure west of the sun should be receding with an equal speed. It cannot be said that the observations for rotation have been successful, though the differ-

ence of observed wave-lengths is in the right direction. The chief difficulty lies in the apparent fact that the green line is not strictly monochromatic. Recalling the lumpy appearance of the green coronal ring, we should perhaps be prepared for the probability that there is motion within the green ring, such that the line as observed by us is widened by radial velocity differences, and not reliably measurable.

#### THE WAVE-LENGTHS OF THE CORONAL BRIGHT LINES.

Much remains to be done in determining the accurate wave-lengths of the coronal bright lines, in preparation for the chemical identification of these lines. There are at least half a dozen coronal lines whose position in the spectrum are determinable, with suitable apparatus and care, much more accurately than they are now known. Probably the best procedure is the unambitious one of attempting to determine the position of only one line, or at most two neighboring lines, with one instrument, exposing with as high dispersion as good judgment dictates; covering with a narrow diaphragm the region of the plate occupied by the coronal line while impressing the appropriate arc or spark spectrum of an element, both shortly before and shortly after the total phase of the eclipse.

#### THE BRIGHTNESS OF THE CORONA.

The photometry of the corona is a problem worthy of further attention, especially with reference to coördinating the laws of coronal brightness with the sunspot phase. Studies in this field should take into account the distribution of the coronal radiations throughout the spectrum. The contrasting of the spectral photometry of the outer, middle, and inner coronal structures is a most promising problem, and the preparing of suitable apparatus, on the basis of optical parts already existing in abundance, should be a simple matter.

#### THE FLASH SPECTRUM.

The so-called flash spectrum of the sun's edge at the second and third contacts should, in my opinion, be observed with instruments specially and carefully designed, and adjusted with great care, to



obtain improved data as to the limiting depths of the strata responsible for the various solar absorption lines.

#### CONTACT TIMES.

The times of contact of sun and moon have been more extensively observed than any other eclipse phenomena. It has long seemed to me that the first and fourth contacts, that is, the instants of time when the moon's image first touches the sun's, and when the moon's image finally leaves the sun's, are not worthy of much attention, and our expeditions have taken no interest in them. The time of the first contact is bound to be uncertain. The observer who is watching for it suddenly realizes that the moon has covered a bit of the sun. How many seconds earlier the contact really occurred he does not know. He is simply aware that it has occurred, and several seconds of uncertainty are unavoidable. The fourth contact can be observed with considerably more accuracy, but a first contact of equal accuracy does not exist to balance it. The second and third contacts, on the contrary, can be observed quite accurately. Nevertheless, the brilliant points continuing to exist at contact II. after the general outline of the moon's edge has passed beyond the sun's corresponding edge, owing to depressions in the lunar surface—and similarly at contact III.—introduce some uncertainty. It seems to me that very valuable comparisons of the relative positions of the sun and moon could be obtained by a series of large-scale photographs, using cameras forty feet or more in length, made near contacts II. and III., under conditions carefully devised for reducing the brilliancy of the solar crescents and for the accurate recording of the observation times.

#### THE ACCURATE POSITION OF THE MOON.

It is very advantageous to eclipse observers that meridian observations of the moon's position be made in months immediately preceding the eclipse date, as a basis for predicting the time when totality will begin at any station on the shadow path. The eclipse of 1918 came seventeen seconds of time earlier than the Nautical Almanacs had predicted three years in advance, three seconds later

than Professor Tucker's recent observations of the moon's position had indicated, and two seconds later than the chronometer time set down on the program prepared an hour before contact II. for the guidance of the observers.

#### THE EINSTEIN EFFECT.

The search for the so-called Einstein effect has become an important eclipse problem. It is well known that recent hypotheses of the nature of light require that rays from distant stars on their way to the eclipse observer, and passing close to the sun's edge, should be drawn toward the sun in appreciable amount while passing through the sun's gravitational field. This would cause a minute displacement of the stellar images upon the photographic plate. Photographs of the region immediately surrounding the eclipsed sun were secured by the Crocker Expedition on June 8, 1919, and photographs of the same region of the sky were obtained with the same instrument set up at Mount Hamilton in January of the present year. If the Einstein effect is a reality, a comparison of the two sets of plates, one obtained with the sun in the field of observation, and the other with the sun absent, should show slight and systematic differences in the angular separation of pairs of stars on opposite sides of the eclipsed sun's position. Owing to war service on the part of our astronomer who secured the photographs for this problem at the eclipse, the plates have not yet been measured. It is hoped that they will receive attention in the month of May.

In securing both sets of Einstein photographs, the driving clock should be reliable, and the observer should "guide" in right ascension on a bright star in the immediate neighborhood of the sun. A guiding telescope of three, four, or five inches aperture and of focal length equal to that of the Einstein cameras and making an appropriate angle with the axes of the cameras, should be able to pick up the image of the selected bright guiding star a few seconds before contact II.

#### THE VULCAN PROBLEM.

In view of Dr. Perrine's results of searches for unknown bodies revolving around the sun, made under the auspices of the Crocker



Eclipse Expeditions to Sumatra, Spain, and Flint Island, it seems sufficient to let the progress of this problem in the immediate future depend upon the Einstein photographs of the sun's surroundings.

#### OTHER ECLIPSE PROBLEMS.

Many other eclipse problems, perhaps of lesser importance from the astronomical point of view, cannot be considered here for lack of time. It is hoped that enough has been said to show that total solar eclipses have raised difficult and interesting questions.

LICK OBSERVATORY,  
UNIVERSITY OF CALIFORNIA.

## THE EXPEDITION OF THE MOUNT WILSON OBSERVATORY TO THE SOLAR ECLIPSE OF JUNE 8, 1918.

By J. A. ANDERSON, PH.D.

(Read April 25, 1919.)

The apparatus of the Mount Wilson Observatory expedition at Green River, Wyoming, consisted of:

1. Littrow Plane Grating Spectrograph. Observers: Adams, St. John and Brackett.
2. Corona Rotation Prism Spectrograph. Observers: Adams and Ellerman.
3. Objective Grating Spectrograph. Observers: Anderson and Babcock.
4. Objective Prism Polarizing Spectrographic Camera: Anderson and Babcock.
5. Eight inch thirty-foot Photoheliograph Camera: Mr. Ellerman.
6. Small Silvered Quartz Lens Camera: Miss Margaret Hale.

Light was supplied to all of these except (3) and (6) from the thirty-inch cœlostæt mirror of the Snow telescope. (3) was fed from a small speculum mirror mounted on the cœlostæt axis, while (6) was simply pointed directly at the sun, and the image allowed to drift.

The general arrangement is shown in the plan sketch (Slide 1). The beam of light from the cœlostæt mirror is directed horizontally westward; the lower central portion falls on the eight-inch photoheliograph lens, the portion immediately north of this serving to fill the two-inch lens of the polarizing spectrograph camera. The upper central portion falls on the six-inch image-forming lens of the corona rotation spectrograph, while the considerable portion left of the south half of the beam sufficiently fills the concave mirror which forms the image used by the Littrow Plane Grating Spectrograph. This spectrograph was located east of the cœlostæt, and



the axis of the concave mirror was inclined to the south and upwards sufficiently to allow the beam to clear the cœlostæt mounting, the angle being a matter of about  $3^{\circ}$ .

This arrangement which is unusually compact even for eclipse work was found to work very satisfactorily indeed, and on account of its compactness it was a simple matter to protect all the instruments from the heat of the sun, as well as from vibration due to the wind.

The Littrow spectrograph consisted a 6-inch aperture, 18-foot focus lens, and a plane grating having a ruled surface of  $4 \times 6$  inches, 15,000 lines per inch, one first order being extremely bright. The dispersion was about 3.4 A.U. per millimeter, which was judged sufficient for accurate wave-length determinations. The diameter of the moon's image formed by the projection mirror was about three inches, and this image was placed just tangent to the slit, the point of tangency being nearly coincident with the position of second contact. During mid-totality, the whole spectrograph was moved parallel to itself a distance of three inches so that during the last half of totality the slit was tangent to the moon's limb at or near the point of third contact. An auxiliary  $90^{\circ}$  prism and observing eyepiece enabled one of the observers to watch directly the region of the spectrum including  $D_3$  for purposes of accurate guiding. Two small right-angled prisms placed over the slit allowed on iron arc comparison spectrum to be impressed on each plate simultaneously with the exposure on the sun. The exposures were six in number, three made during the total phase and three before and after, in order to get accurate wave-lengths extremely close to the sun's limb.

The corona rotation spectrograph was a three-prism Littrow type, using a lens of forty-inch focus, the dispersion at  $\lambda 5300$  being about six A.U. per millimeter. Only that portion of the spectrum in the immediate vicinity of the green coronal line was photographed, the slit being parallel to the sun's equator. An iron arc comparison spectrum was impressed immediately before totality so as to permit an accurate determination of the wave-length of the green line.

The objective grating spectrograph used a six-inch Rowland

concave grating of twenty-one-foot radius of curvature, and was of exactly the same type as has been used at various eclipse observations before. One improvement in the method of observation needs, however, to be noted: Ordinarily the spectrograph is adjusted with the axis of the incident beam pointing to the center of the sun. For a station near the center line of the eclipse track the direction of the incident light at second and third contacts, make angles of  $\pm 15'$  with this direction, which alters the focus of a grating such as was employed here by a quantity of the order of one millimeter. In the present case the speculum mirror being adjusted to the center of the sun before totality was rotated eastward through an angle of seven and one half minutes for the exposures at second contact; then back to the original position for the exposure at mid-totality; then westward seven and one half minutes for the remaining exposures at third contact.

The objective prism polarizing spectrograph consisted of an ordinary  $4 \times 5$  view camera having a two-inch aperture, eight-inch focus Planar lens, in front of which was placed in order a direct vision prism and a Rochon double image prism. Two objective prism spectra are thus obtained, the planes of polarization being at right angles to each other.

The silvered quartz lens camera was used simply to obtain data in regard to exposure time and relative aperture required for use at future eclipses. As is well known a silver film opaque to visible radiation is quite transparent from about  $\lambda 3200$  to  $\lambda 3100$ . Used on a quartz lens it is hence possible to obtain fairly monochromatic images in this part of the ultra-violet spectrum. In the present case the aperture was about  $F/12$ , the exposure time through clouds with an estimated transparency of 10 per cent., about ninety seconds, and yet a great deal of coronal structure is well shown on the plate obtained. Hence it should be easy to obtain good photographs in this way when conditions are right.

On the day of the eclipse a large cloud obscured the sun from a few minutes after first contact until a few minutes after third contact. During totality the sun was visible through an irregular thinner portion of the cloud, but it is doubtful if the intensity of the



light was more than 10 per cent. of normal. However, the program was carried through as planned.

The photographs obtained with the photoheliograph were fairly good as may be seen from the slides (2 and 3). The plates taken with the Littrow plane grating spectrograph were too weak to be of value, as was also the case with those obtained with the objective grating spectrograph. The latter shown about a dozen of the ultra-violet hydrogen lines, and the prominences in the stronger hydrogen lines and in H and K show well. The irregular prominence shown on slide 2 shows some distortion due probably to motion in the line of sight.

The plate taken with the corona rotation spectrograph shows the coronal line only at the east limb, hence the rotation cannot be determined. The wave-length at E limb neglecting the rotation comes out equal to 5303.022 Å.

MOUNT WILSON OBSERVATORY,  
PASADENA, CALIF.

## THE LOWELL OBSERVATORY ECLIPSE OBSERVATIONS, JUNE 8, 1918.

### PROMINENCES AND CORONAL ARCHES.

By C. O. LAMPLAND.

(*Read April 25, 1919.*)

The solar prominences or protuberances have considerable historical interest in the part they have taken in the advances made in our knowledge of the constitution of the sun. These beautiful formations, varying in color from deep ruby to pale pink, projecting outside of the dark disk of the moon upon the background of the pearly luster of the corona at times of totality caught the attention of earlier observers and we may have references to them extending back two hundred years. They came to occupy a conspicuous place in the eclipse literature of 1842, and Dr. Lockyer remarks of this eclipse in connection with the prominences, "then the golden age begins." But whether they belonged to the moon or the sun was a question that was not definitely decided until De la Rue's photographic observations of the eclipse of 1860. His series of exposures during totality showed beyond doubt that the prominences on the opposite edges of the sun were progressively covered and uncovered by the disk of the advancing moon. At the present day it may help us to sympathize with the difficulties of these earlier investigators to recall our own helplessness, and how we are apparently marking time, on some of the outstanding problems of the corona.

Our knowledge of the more complex structure of the inner corona by direct observations has been largely obtained by photography, and noteworthy progress has been achieved during the last twenty-five years. Large-scale photographs, suitable sensitive plates, and graduated series of exposures may be mentioned among some of the things that have contributed to the advances made.



In the present paper a brief account will be given of some preliminary observations of the prominences, of coronal formations over them, and of some of the complex structure of the inner corona, shown in the series of photographs obtained by the Lowell Observatory Eclipse expedition stationed at Syracuse, Kansas.

The photographs were made with two of the historic "Transit of Venus" objectives kindly loaned by the U. S. Naval Observatory. These objectives have an aperture of five inches and a focal length of 38.7 feet. They were mounted according to Schaeberle's method. The tower camera and its moving plate carrier have been so frequently described, and the method is so well and favorably known among astronomers that no time will be taken here for the description of the apparatus.

In connection with the description of some of the detail in the Lowell Observatory photographs quotations and illustrations from published observations of earlier eclipses will also be given, but such references must necessarily be very brief and incomplete at this time. It is thought that these comparisons should be both interesting and instructive.

A brief description will now be given of the more interesting features of the Lowell Observatory photographs.

P.A.	Description of Detail.
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25°	A coronal arch. No prominence visible.
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30°.5	Brilliant short prominence.
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51°.5	Large brilliant triangular-shaped prominence, base resting on chromosphere. Fine series of coronal arches, four or more, over this great prominence. Branches of the higher arches not symmetrical with respect to prominence but as if partially superposed from perspective displacement.
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99°.5	Small bright prominence inclined (N. and W.) to solar surface about 45°. It is centrally in great mass of brilliant coronal matter. Indications of arches but detail cloud-like or flocculent in parts.
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- 162°. A group of three brilliant prominences near south pole;  
to positions of centers of these prominences about 165°,  
182° 172°.5, and 179°.5 (position of south pole of sun 167°.4).  
Very bright coronal matter over the group. Strong hood  
or arch over the first two prominences; part of an arch over  
the third (named in order of increasing P. A.).
- 186° A large bright "petal" of coronal matter over the brilliant  
to flame-like prominence in position angle 205°. A closely  
226° packed series of arches, all of the pointed or ogival type,  
except possibly the inner one. At least six of these arches  
stand out distinctly. The highest ones very sharply  
pointed, and the apexes, with increasing height, are to one  
side of the center of the prominence, as though the dis-  
placement were an effect of perspective.
- 231° Another large brilliant "petal" of coronal matter, with the  
to great eruptive prominence centrally in its base (P. A. of  
270° center of prominence about 251°). At least five arches are  
visible. In this instance the arches are oval curves, and not  
pointed at the vertices. The arches are somewhat skewed,  
the inclination being in the same direction as the trunk of  
the great skeleton prominence they enclose. A comparison  
of the Lick and Lowell plates shows marked changes in  
the eruptive prominence.
- 233°.5 Base of the "rocket" prominence.  
The higher part of the trajectory of this eruptive forma-  
tion or jet is not certainly shown on the Lick plates taken  
about 27<sup>m</sup> earlier. On the Lowell plates the upper part  
of the curve is clearly shown and the brilliant nucleus has  
apparently passed its greatest height and is descending.
- 270° Very brilliant "petal" of coronal matter, with large bril-  
to liant prominence centrally (P. A. of base of prominence  
320° extends from 288° to 301°). Complex detail above the



prominence—cloudy and flocculent— with indications of confused and overlapping arches.

- 351°.5 Prominence near the north pole.  
225° Pronounced rifts in the corona occur near these points,  
and the latter inclined, near limb, 20° or more southward with  
270° the radius.
- 35° Four narrow and well-defined dark rays in brilliant coronal  
to matter, inclined a few degrees, northward, with the radius  
40° where rays start from the limb, but with gentle bending  
southward towards the equator with increasing distance  
from the limb. A number of broader and more diffuse  
dark lanes and streaks occur in different parts of the corona.

Any detailed description of the appearance, distribution and directions of the coronal rays for different regions will not be given here. The variability and irregularity of their inclinations with respect to the limb of the sun suggests the maximum type of corona, though in some other respects characteristic features of the intermediate type are present, as for example the general shape of the corona as a whole is roughly triangular.

In the Lowell Observatory photographs all of the prominences except the one near the north pole are surrounded by arches or envelopes or of disturbed coronal matter. Above some of the prominences there are series of hoods or arches the forms of the inner or lower ones being generally some oval curve, while the outer or higher ones have forms resembling the pointed or ogival arch.

One striking feature of these photographs is the disturbance of the coronal streamers at and in the vicinity of the sun's poles. In that respect the corona of 1918 resembles earlier ones observed near sun-spot maxima, though as previously remarked it exhibits other features characteristic of intermediate types. In the present photographs it would be difficult to estimate the position of the poles of the sun from the appearance of the streamers.

That there is an intimate relation between the prominences and the surrounding coronal structure has at different times been ex-

pressed by observers of the more recent eclipses. But these relations are not always evident as will be shown by extracts from published observations of eminent observers and students of eclipse phenomena. It is probably true that hoods and envelopes over the prominences are generally present but are greatly reduced in intensity or may even be absent for a short time near sun-spot minima and it is also probably true that such detail and complex structure in the inner corona are generally conspicuous at times of greater solar activity.

From an extensive examination and careful study of many photographs of the corona beginning with the eclipse of 1851 and continuing with the later eclipses of 1860, 1870, 1871, 1875, 1878, 1882, 1883 and 1885, an eminent authority on eclipse photographs writes: "There is no sign of any connection between the coronal rays and the solar prominences." It would seem, however, that the present trend of the interpretation of observational results is that the prominences generally do affect to a marked degree coronal structure in their vicinity.

The complex coronal structure, arches, etc., of the eclipses of 1871, 1883, 1893, 1905 and 1918 occurring at or near times of sun-spot maxima, and the almost complete absence of such intricate and complicated detail of the lower regions of the corona of the eclipses occurring at or near the minima of sun-spot activity in 1878, 1889 and 1900 may be mentioned in this connection. The eclipses at the minimum epochs were so fully and so successfully observed that it is difficult to believe that such structure could have been overlooked. The reports for 1900 by Hale, Langley, Newall, Wesley and others are especially complete in this respect as specific mention is made with reference to search for such detail. It also appears from the observational results that the complex detail in question is present in varying degrees for eclipses observed preceding or following minima of solar activity. The eclipses of 1896 and 1898 are good examples of eclipses that fall between a maximum and minimum.

The question of changes taking place in detail in the corona in the interval between observations made at different stations is one of great interest and we are not aware that a definite answer



has yet been given in the previous attempts to decide the matter. It was hoped that it might have been possible to include some satisfactory observations in this communication. The preliminary work done thus far does not warrant a stronger statement than to say that further comparisons should be made, at least in the case of one of the series of prominent arches. Unfortunately the material at present available is not wholly satisfactory for such difficult comparisons. As prominence detail is frequently subject to rapid change it does not seem worth while to add anything further than already given relative to such comparisons. The marked changes that occurred in the great eruptive prominence are obvious upon casual inspection.

Our appreciative thanks are due to Dr. Campbell for generously granting permission to make use of three very fine positives from plates of short exposure taken at Goldendale, sent us recently.

Dr. Slipher gives herewith a summary of his observations of the spectrum:

#### SPECTRUM OBSERVATIONS OF THE CORONA.

The spectrograms recorded a strictly continuous spectrum for the inner corona crossed by the three coronal emissions of wavelengths 4086, 4231 and 5303.0; and a faint solar dark-line spectrum for the outer corona which seems to be of true coronal origin. The objective prism plates registered the continuous spectrum of certain prominences in addition to their usual emissions, and the green coronium ring between the fragmentary ones of hydrogen F and helium D<sub>3</sub>. The distribution of the intensity of the green ring implies that the substance "coronium" is generally abundant along those parts of the sun's limb occupied by prominences and from which flow the great extensions of the corona, and that it is sparse along those sections of the limb occupied by the bristling streamers typical of the polar regions.

The observational results given in the present paper are the joint work of Dr. V. M. Slipher, Mr. E. C. Slipher and the writer. A general account of the organization and work of the expedition has been published in one of the astronomical journals.

LOWELL OBSERVATORY,  
FLAGSTAFF, ARIZONA.

## THE FLASH SPECTRUM.

By S. A. MITCHELL.

*(Read April 25, 1919.)*

The total eclipse of 1918 saw the completion of fifty years since the spectroscope was first used at the eclipse of 1868, visible in far-off India. If all the minutes of totality during this half century of eclipses were added together, they would amount to less than one brief hour. It is safe to say, however, that no other branch of astronomy has shown the remarkable value of the new instrument of research as has the work of eclipse spectroscopy.

In 1868, Janssen discovered that the prominences gave a bright line spectrum thus proving that they are gaseous in nature. As is well known, he and also Lockyer independently, showed how to view the prominences without an eclipse.

The year 1869 brought with it the discovery of helium in the sun. Since the urgency of the war has resulted in having helium supplied in such large quantities and at such a cheap price that it may be used in balloons and airships, it is almost a surprise to think that helium was not discovered by Ramsay until the year 1895.

The eclipse of 1870 visible in Spain is noted for the discovery of the flash spectrum. The dark lines in the solar spectrum, the Fraunhofer lines are caused by the absorption of the light of the photosphere by a thin layer of cooler gases, the so-called reversing layer. This layer is cool only in contrast with the very hot photosphere. As the moon gradually covers the sun at the time of an eclipse the dark line spectrum persists so long as there is even the slightest trace of the photosphere visible. At the instant when the photosphere is entirely covered up, the bright photospheric background of the Fraunhofer spectrum is removed, and the lines of the spectrum now appear as bright lines on a black background, where before there had been dark lines on a bright background. This change coming with totality was foretold by Young of Princeton before the



eclipse of 1870, and his was the first eye to perceive it. The suddenness of the change caused him to name the bright line spectrum the "flash spectrum." At the beginning of totality, the flash spectrum lasts for only a few seconds while the moon is advancing in front of the rather shallow layer. A second flash spectrum is seen at the end of totality.

The first attempt to photograph the flash was in 1893, but with very imperfect results. Shackleton in 1896 was more successful, though the first photographs with good definition were those of the eclipse in India in 1898 by Evershed.

In the year 1900, the American astronomers had an opportunity in their own country at the eclipse of May 28. For the first time in eclipse work, Rowland gratings were used. Gratings are ruled on both plane and concave surfaces, and it is possible to use them either with or without a slit. The great advantages of gratings over prisms are the increased dispersion, but particularly their normal spectrum. When used in the ordinary Rowland mounting, the concave grating shows marked astigmatism. Although work on stars had shown that the astigmatism of the concave grating when used directly without slit was exceedingly small, most observers in 1900 were apparently afraid to use a concave grating without a slit. Those who did use slits found their photographs entirely without lines, the light that went through the slit being entirely too feeble to leave any impression on the photographic plate. Gratings used without slits gave more satisfactory results.

Since 1900, the eclipses most easily observed were the Sumatran eclipse of 1901, the Spanish eclipse of 1905, the Flint Island eclipse of 1908, the Russian eclipse of 1914, and the American eclipse of 1918.

When great dispersion is desired, the concave grating without slit is perhaps the most desirable form of spectrograph. Its mounting is very simple. Light from the cœlostat mirror falls direct on the concave grating where it is diffracted and brought to a focus on the photographic plate. It might not be out of place here to call attention to the great importance, and also the great difficulty, of obtaining sharp focus with the slitless instrument. The best results

have been obtained by the writer through the use of a collimator designed by Jewell.

In 1905 with a Rowland concave grating of 15,000 lines per inch, Mitchell secured a photograph of the flash spectrum in which he measured 2,841 lines between  $\lambda$  3300 in the violet, and the  $D_3$  line in the yellow. On account of the good definition, it was possible to determine wave-lengths to 0.02 Ångstroms corresponding to an error of measurement of 0.002 mm.

The general conclusions from these measures were:

1. The flash spectrum is a reversal of the Fraunhofer spectrum.
2. The flash is not an instantaneous appearance, but the chromospheric lines appear gradually. At the beginning of totality, those of greatest elevation appear first, and at the end of totality remain the last. The "reversing layer" which contains the majority of the low-level lines is about 600 km. in height.
3. Wave-lengths in the chromospheric and solar spectrum are practically identical.
4. The lines in the chromospheric spectrum differ greatly in intensities from the lines in the solar spectrum. The chromospheric spectrum shows the hydrogen series of lines and the helium lines and corresponds to a spectral type earlier than the solar spectrum.
5. The differences in intensities find a ready explanation in the heights to which the vapors ascend.
6. Especially prominent in the chromosphere are the enhanced lines.

In view of the very excellent work done recently at Mt. Wilson, it has become of the utmost importance to have as accurate a knowledge as possible of the heights of the various layers of the sun's chromosphere above the photosphere. There is no other method of determining these heights directly except from the photographs of the flash spectrum at the time of a total eclipse taken without slit. By knowing the angular diameters of sun and moon, it is easy to calculate the height of the solar layers of atmosphere by measuring the lengths of the cusps. On the photograph a spectrum line of considerable length corresponds to a greater height of atmosphere, while a shorter line belongs to a low-lying vapor.



The program of work on the flash spectrum at the eclipse of 1918 was for the purpose of finding the heights of the various gases, and also of extending our knowledge of the spectrum as far into the red as possible. The Naval Observatory party located in Baker, Oregon, had three concave gratings, the largest being of  $21\frac{1}{2}$  feet radius and 15,000 lines in order to procure as large a dispersion as possible; the second grating was of 10 feet radius and 15,000 lines, while the third was of small dispersion to photograph into the extreme red by the use of plates stained by dicyanin. Unfortunately, thin clouds covered the sun during the whole of totality. The clouds at the end of totality were exceedingly thin, but they were sufficient to cut out most of the weaker lines from the spectra. At no place in the country where photography of the flash spectrum with great dispersion was attempted did clear skies prevail; and consequently the carefully prepared plans for 1918 will have to be tried again at the next available eclipse.

McCORMICK OBSERVATORY,  
UNIVERSITY OF VIRGINIA.

## PHOTO-ELECTRIC PHOTOMETRY OF THE 1918 ECLIPSE.

BY JAKOB KUNZ AND JOEL STEBBINS.

(Read April 25, 1919.)

The expedition from the University of Illinois had for the sole item on its program the measurement of the total light of the corona by means of photo-electric cells. The arrangement consists of a light-sensitive cell connected in series with a galvanometer and a battery giving about 150 volts. When exposed to a light about equal to that of the crescent moon, a measurable current is produced, and it was anticipated that the corona would be bright enough to be measured with accuracy. The advantage of this electrical photometer is that no matter what the distribution of light is in the source, whether it be a point or an irregular surface, the effect is integrated and is combined into a single galvanometer deflection.

The color-sensitivity of the potassium cell is nearly like that of the ordinary unstained photographic plate, the maximum effect being at wave-length 4500 Å. In a general way, the photo-electric measures are between photographic and visual, but nearer the former.

*Slide 1* shows one of these cells, the diameter of the bulb being about one inch.

*Slide 2.*—The station at Rock Springs, Wyoming, was selected so as to be near the Yerkes camp, where Mr. Parkhurst was to undertake visual photometric measures of the corona, for it was felt that there would be advantages in having observations by different methods, but with practically the same atmospheric conditions. However, we did not want a local cloud to spoil all of the photometry, so we located about fifteen miles east of the Green River people, and about two miles south of the town of Rock Springs.

*Slide 3.*—General view of the station.

*Slide 4.*—It was proposed to take measures in duplicate with two cells, each mounted in a box at the lower end of a simple tube. The



twin tubes were fastened on an equatorial mounting, but a driving clock was unnecessary. (Note: the simple tubes were made of four-inch down-spouts.)

*Slide 5.*—The electrical connection from each cell was carried in conduit to the galvanometer and battery inside the hut. Each cell box could be detached from the mounting outside, and brought in to the photometer bench. Here it was arranged that the cell could be exposed to a standard amyl acetate candle at varying distances, and also to standard low-voltage electric lamps. The same apparatus was also used to compare the lamps with the full moon, and thus to get an indirect measure of the corona in terms of moon light.

*Slide 6.*—Two assistants operated the apparatus outside, while the observers read the galvanometers.

*Slide 7.*—Our expedition had the same unfortunate experience with the weather that other parties had on the days preceding the eclipse. The nights and early mornings were usually clear, but clouds, increasing during the day, were usually worst about the hour of the eclipse, 5 P.M. The picture shows the conditions thirty minutes before totality.

*Slide 8.*—At six minutes before the critical time the sun was still behind the cloud at the upper left-hand corner of the picture, but at two minutes before time the cloud had moved away, and during totality the corona stood out in a perfectly clear sky.

#### RESULTS.

We secured four complete measures of the light of the corona, and of the sky background. When proper allowance is made for the absorption of the earth's atmosphere, it is found that the total light of the corona was 1.07 candle meters, just half the light of the full moon. There has been a curious disagreement between observers at previous eclipses, as values have been found ranging from one fortieth to ten times the moon's light, a difference of 400-fold. These were results from photographs, but the more reliable determinations seemed to indicate a value of one tenth full moon, five times smaller than our value. The visual results are in much better agreement, ranging from half up to one full moon, or from the same up to twice our value.

Our comparison of the corona with the sky before and during the eclipse shows that, in terms of a circle of sky of the apparent size of the sun, the corona gave one tenth as much light in full sunshine, but more than 600 times as much during totality. The decrease in the light of the sky due to the moon's shadow was therefore 6,000-fold. As the decrease from sunlight to corona light is fully 100 times 6,000, this means that not more than 1 per cent. of the general sky illumination during an eclipse can come from the corona, the remainder being from sunlight reflected from the earth's surface and atmosphere which is outside the moon's shadow.

The result that the corona gives one tenth of the light from a circle of daylight sky of the same area as the sun, and  $8^{\circ}$  away, has a direct bearing upon the problem of detecting the corona without an eclipse. Experiments in using photo-electric cells for this purpose have already been begun by Dr. Hale at the Mt. Wilson Observatory.

UNIVERSITY OF ILLINOIS,  
OBSERVATORY.



THE SPROUL OBSERVATORY ECLIPSE EXPEDITION,  
JUNE 8, 1918.  
CORONAL ARCHES AND STREAMERS.

By JOHN A. MILLER.

*(Read April 25, 1919.)*

The Eclipse expedition from Sproul Observatory was located at Brandon, Colo., a station on the Missouri Pacific, approximately fifty miles from the Colorado-Kansas line.

This region is very dry, and the weather conditions are favorable. During the month preceding the eclipse the sun was either clear or only thinly clouded, at 5:26 P.M. on all but six days; and in general the afternoons were better than the forenoons. The wind was usually high, often very high, and the air many times was full of dust. It was so cloudy all day on June 5, 6 and 7, and the forenoon of June 8, that at no time could successful observations have been made. This was the longest period of cloudy weather that we had while there. At noon of June 8, however, it cleared, and at the time of totality only two small clouds were visible west of the meridian, one about twenty degree above the sun and the other near the horizon. The seeing was fairly steady.

The following instruments were mounted:

I. One lens, nine inch aperture, focal length  $62\frac{1}{2}$  feet. This was mounted as the Lick Observers since 1893 have mounted their long focus lenses. Exposures of two seconds, twenty seconds, forty-five seconds, and three seconds were made with this lens.

II. On a polar axis, two lenses of four inches and three and one half inches aperture, respectively, and of focal length eleven feet two inches were mounted. The exposure with each of these lenses was for eighty-two seconds.

III. In another polar axis were mounted six lenses varying in focal length from ten and one half to fifty inches; also a transmission grating.

IV. A three-prism slit spectrograph with which we hoped to

determine the rotation of the corona, and a slitless spectrograph were mounted on another polar axis.

The photographs secured show a mass of coronal detail. The shorter exposures show the coronal arches that surround the great number of prominences that are found on the rim of the sun. These have been so well shown in the slides accompanying the preceding papers that it seems unnecessary to show them again and for economy of time I shall show one only, a slide from the forty-five second exposure with the sixty-two and one half feet focal length.

The problem that I had more specifically in mind was to secure if possible some data that would contribute to a knowledge of the origin of the corona, to see if we could from a study of the details of its structure get a hint of the nature of the forces that produce it and give it its shape. I shall limit myself to a brief statement of our study of two things.

1. To see if there was any indication of change of form in the corona itself during the eclipse.
2. To find if the general form of the streamers in the corona gave any indication of the way in which it is formed.

#### I. CHANGE IN THE CORONA.

Director Campbell, of the Lick Observatory, and Professor J. C. Hammond, Director of the Naval Observatory Station, most generously put at my disposal glass positives of short exposure photographs, made respectively at Goldendale, Washington, and Baker City, Oregon. The Lick plate was made with a camera whose focal length is forty feet. Totality at Goldendale lasted for one minute and fifty-seven seconds. The plate loaned me by Director Campbell was exposed from one minute fifty seconds to one minute fifty-two seconds after the beginning of totality. This plate was compared with two plates made by the Sproul Observatory expedition, one exposed for two seconds just at the beginning of totality and the other for three seconds just at the end of totality. The focal length of the camera with which these plates are made is sixty-two and one half feet, so that the pictures to be compared were of very



different scales. The plates were reduced to the same scale by measuring the diameter of the moon's shadow on each plate and finding the ratio of these two measured diameters. The center of the sun for each of the three plates was found and plotted on each plate, the necessary corrections being made for different times of exposure, parallax, etc. The conspicuous prominences were as follows: Two small quiescent northern prominences, a large northwestern quiescent prominence, a large eruptive prominence in the southwest called from its shape the Skeleton prominence, and a large northeastern prominence called the Pyramid prominence.

Around the eruptive prominences there are series of arches described so well in the preceding paper by Professor Lampland that further comments are unnecessary.

Following my suggestion Miss Margaret E. Powell, a graduate student at Swarthmore College, made a study of these plates. All the measures which I shall give presently were made by Miss Powell. We selected three arches which seemed definite enough to measure.

The measures were made in this way. A point is selected which can be certainly identified on each of the three plates. Choosing a line through this point and the center of the sun as an initial line and the center of the sun as origin, we may locate any point in the streamer by its polar coördinates  $\theta$  and  $\rho$ . The arches were about equally well defined in the Lick plates and each of the two Sproul plates. The polar coördinates of a series of points on an arch were measured on the Lick plate, then setting off the same series of vectorial angles on a Sproul plate and measuring the radii vectors, we obtained the polar coördinates of the corresponding points on the Sproul plate. If these radii vectors are the same the arch is unchanged, but if they are different (assuming the measures are exact) the shape or the position of the arch has changed.

Miss Powell measured three arches in this way. The accompanying tables give the details of the measures. The vectorial angle is given by  $\theta$ . The quantities  $\rho$  and  $\rho'$  are the radii vectors in inches measured on the Sproul and Lick plates respectively and reduced to the scale of the Sproul plate.

The eclipse at Brandon occurred twenty-five minutes after it

occurred at Goldendale;  $\rho - \rho'$  is therefore the amount the arch has changed. If  $\rho - \rho'$  is positive for a given point, that point is farther from the center of the sun, when the sun was eclipsed at Brandon than when it was eclipsed at Goldendale twenty-five minutes before.

After the first set of measures was made, the zero line was re-determined and all angles and distances remeasured, so that each set of measures was independent of the others except the same size of each vectorial angle was retained. The different series of measures were made on different days, the last series being made about six weeks after the first were made, so that I believe little, if any, prejudice originating in the earlier measures was carried into the last set.

*Measures of the Arch Around the Southeastern Prominence.*—This prominence is a few degrees east of the South Pole. There are five well defined arches on the equator side of this prominence, the inner one of which is measured. The table shows the results.

#### 1. AN ARCH AROUND THE SOUTHEASTERN PROMINENCE.

	First Measures.				Second Measures.			Third Measures.			
	$\rho$	$\rho'$	$\rho - \rho'$	$\theta$	$\rho$	$\rho'$	$\rho - \rho'$	$\rho$	$\rho'$	$\rho - \rho'$	$\theta$
1.	3.81	3.71	+0.10	+1° 48'	3.84	3.76	+0.08	3.84	3.76	+0.08	+1° 48'
2.	3.88	3.71	.17	1 18	3.91	3.76	.15	3.91	3.80	.11	1 18
3.	3.91	3.76	.15	0 48	3.94	3.84	.10	3.94	3.84	.10	0 48
4.	3.94	3.84	.10	0 24	3.97	3.88	.09	3.97	3.88	.09	0 24
5.	3.97	3.88	.09	-0 18	3.97	3.93	.04	4.00	3.93	.07	-0 18
6.	3.97	3.88	.09	-0 36	4.00	3.93	.07	4.00	3.93	.07	-0 36

The quantities  $\rho$  and  $\rho'$  in the "first measures" of this arch are from center of the sun to the inner boundary of the arch; the other measures from this arch and all the others are to the middle of the stream forming the arch. The first measure in each series is always for a point near the limb of the sun, and is in consequence very indefinite.

#### 2. AN ARCH AROUND THE PYRAMID PROMINENCE.

Toward the Pole side of this prominence there are four well-defined arches; one of these was measured. The arches on the Brandon plates seem to curve more than those on the Goldendale plates. The results are shown of four sets of measures on three different days.



	First Measures.				Second Measures.			Third Measures.			
	$\rho$	$\rho'$	$\rho-\rho'$	$\theta$	$\rho$	$\rho'$	$\rho-\rho'$	$\rho$	$\rho'$	$\rho-\rho'$	$\theta$
1.	4.06	4.14	-0.08	+1° 36'	4.09	4.01	+0.07	4.09	4.05	+0.04	+1° 36'
2.	4.28	4.27	+ .01	2 12	4.28	4.23	.05	4.28	4.18	.10	2 12
3.	4.38	4.31	.07	2 36	4.38	4.23	.15	4.38	4.23	.15	2 36
4.	4.41	4.35	.06	3 30	4.47	4.27	.20	4.47	4.31	.16	3. 30
5.	4.47	4.40	.07	4 18	4.47	4.31	.16	4.47	4.35	.12	4 18
6.	4.47	4.44	.03	4 54	4.50	4.35	.15	4.50	4.35	.15	4 54
7.	4.50	4.48	.02	6 06	4.50	4.40	.10	4.50	4.40	.10	6 06

Fourth Measures.				Fifth Measures.			
$\rho$	$\rho'$	$\rho-\rho'$	$\theta$	$\rho$	$\rho'$	$\rho-\rho'$	$\theta$
1.	4.00	4.10	+0.10	4.06	4.05	+0.01	+1° 36'
2.	4.25	4.18	.07	4.22	4.18	.04	2 12
3.	4.31	4.23	.08	4.28	4.23	.05	2 36
4.	4.34	4.27	.07	4.34	4.27	.07	3 30
5.	4.38	4.35	.03	4.38	4.35	.03	4 18
6.	4.41	4.40	.01	4.47	4.40	.07	4 54
7.	4.41	4.40	.01	4.47	4.40	.07	6 06

## 3. AN ARCH OF THE SKELETON PROMINENCE.

This prominence has five distinct arches on the equatorial side. On the Pole side they are much less distinct, due perhaps to the presence of another prominence beyond the edge of the sun. The measures of the fourth arch from the prominence on the equatorial side are shown in Table 3.

	First Measures.				Second Measures.			Third Measures.			
	$\rho$	$\rho'$	$\rho-\rho'$	$\theta$	$\rho$	$\rho'$	$\rho-\rho'$	$\rho$	$\rho'$	$\rho-\rho'$	$\theta$
1.	4.09	4.01	+0.08	+ 9° 30'	4.09	4.01	+0.08	4.00	4.01	-0.01	9° 30'
2.	4.15	4.10	+ .05	10 24	4.16	4.10	.01	4.09	4.10	+ .01	10 24
3.	4.19	4.18	+ .00	11 30	4.19	4.18	.01	4.19	4.14	.05	11 30
4.	4.22	4.23	- .01	13 06	4.25	4.23	.02	4.25	4.18	.07	13 06
5.	4.23	4.27	- .05	13 42	4.28	4.27	.01	4.28	4.27	.01	13 42
6.	4.28	4.31	- .03	14 42	4.31	4.31	.00	4.31	4.27	.04	14 42
7.	4.34	4.35	- .01	16 00	4.34	4.31	.03	4.37	4.31	.07	16 00
8.	4.38	4.35	+ .02	17 06	4.38	4.35	.02	4.38	4.35	.03	17 06
9.	4.41	4.40	+ .01	17 48	4.41	4.40	.01	4.40	4.40	.01	17 48
10.	4.44	4.44	- .00	18 48	4.44	4.40	.04	4.44	4.40	.04	18 48

Miss Powell found that on the average the recession of the arch around the Southeastern Prominence is (assuming these measures are correct) ninety miles a second; that the recession of the arch around the Pyramid is sixty miles per second and that the Skeleton is receding fifteen miles per second.

The Skeleton Prominence and its arches cover  $37.5^\circ$  along the margin of the sun, the highest arch is 108,000 miles; this means that if these arches are a mechanical effect that a volume of gas of more than 2,540,470,000 millions of cubic miles has been affected.

There are other things suggesting changes of form, but hardly such things as one could measure. It is not unusual for streamers to issue from small projections on the prominences. From each of three tips of the Southeastern Prominence there issues streams each of which assume the approximate form of the arches above them.

In interpreting these measures, one must not be unmindful of the difficulties of these measures and the consequent uncertainty. The streamers themselves are somewhat indefinite objects to measure. An error in plotting the center of the sun on the plates might cause the differences of  $\rho$  and  $\rho'$ . On the other hand, the measures have been very conscientiously made. No one could have been more painstaking than Miss Powell has been. The center of the sun was plotted separately on the plate for the first and for the second measures. Any two series are reasonably consistent, and in one thing they are very consistent— $\rho - \rho'$ , though small, is almost always positive. Moreover, the three prominences are so distributed about the sun's limb that an error in plotting the center should have affected  $\rho - \rho'$  in different ways for different arches. In my judgment these measures make it probable that these arches of the corona changed in the twenty-five minutes between the eclipse at Goldendale and that at Brandon, and that they are going outward from the sun.

The other study is of quite a different nature. There are in every corona a number of streamers, those around the poles of the sun being most conspicuous, but streamers are by no means confined to these regions. In 1911 I published a paper<sup>1</sup> in which I assumed that what we see or photograph as the streamers of the corona are projections on a plane perpendicular to the line of sight, of streams of particles the motion of which is produced by ejection, by the rotation of the sun, by the attraction of the sun and by radiant pressure from the sun. At that time Director Campbell generously placed at my disposal the most excellent series of long focus photographs that had been made by eclipse expeditions from Lick Observatory.

<sup>1</sup> *Astrophysical Journal*, XXXIII., 4, page 303.



I was able to show that if these streamers were thus mechanically produced that there would result in each corona a few streamers of such a shape that one could draw a radius vector from the center of the sun which would be tangent to the streamer and that one could find for streamers of this shape the following things:<sup>2</sup> the point on the sun from which the streamer issued, the velocity with which the particles in it were ejected, the velocity of the particles at any time, the paths described by the particles and if we assume the law of the repulsive force, we can find its magnitude. Theoretically, there should be very few streamers of this shape. In an examination of the Lick plates made at six eclipses between 1893 and 1908, I found sixteen streamers of this type; and on the plate made by Father Cortie at a time of minimum sun-spots in 1914, Miss Caroline Smedley, an assistant at the Sproul Observatory, found and measured two streamers of this type, and in the corona of 1918 there is unmistakably one and probably two streamers of this form. These also Miss Smedley measured and reduced. There always exists the possibility that the form of the streamer has been affected by local causes and the arches which I have just discussed makes it apparent that at least near the surface of the sun at this eclipse local forces were very effective, but the streamers that we found in this corona and which we measured stand out separated from these disturbed regions and away from the prominences.

This theory works admirably with one exception which I shall now discuss. Since the solution gives the form of the paths in which the particles in the streamer are traveling, one should be able to compute an ephemeris for each particle and using the constants determined in the solution compute a streamer that exactly reproduces the streamer from which the constants were found. It turns out that with these constants the streamer on the sunward side of the tangential point *P* and for some distance on the other side of the *P* the streamer can be perfectly represented, but that when we compute the position of the particles at a distance of two or three radii from the sun, that the streamer thus plotted turns back much more abruptly than those do that are shown in the photograph. We have plotted with the constants obtained by the solution several

<sup>2</sup> See Fig. 4, *loc. cit.*

streamers and they all possess this property. This may be interpreted to mean that this mechanical theory of the corona is wrong or that there are other forces acting on these particles than the attractive forces of the sun, and of a repulsive pressure that varies inversely as the square of the distance from the sun's center. It is easy to conceive of many forces such as resistance to motion by gases or that the particles at greatest extension of the streamer were lighter than those forming the part of the streamer measured.

We attempted also to apply Bigelow's earlier theory to the formation of these streamers. Miss Smedley was able to show that if this (Bigelow) theory is true that these magnetic forces alone could produce no streamer of the form described in Figure 4; that is, that the vectorial angle of the radius vector from the center of the sun to any point  $P$  on the streamer either constantly decreases or constantly increases as  $P$  is moved along the streamer away from the sun.

Another phenomena which seems very exceptional in the case of this eclipse occurs in connection with the polar rays. In almost no case are the polar rays arranged exactly symmetrical with regard to the axis of rotation of the sun. But in most coronas the vectorial angle of a point  $p$  decreases as it moves out along a streamer on the west side of the axis of rotation; while for those on the east side the vectorial angles increase; that is, these rays are gently curved away from the axis, but, as I have said, not exactly in a symmetrical way. All these things can be produced under the assumption of the mechanical theory; but in this eclipse the vectorial angle decreases as  $P$  moves out along the streamer whether it is on the east or on the west side of the axis of rotation, and this is true not only of the rays around the north, but also around the south poles. I have not had time to investigate whether or not this is possible under the mechanical theory.

It seems probable to me that the long graceful streamers of the corona, at least the part of them that is at some distance from the sun are largely the product of mechanical influences. The suggestions made by Mr. Lampland in the preceding paper that of certain prominences the inner arches seem to circle around the prominence while the outer arches were pointed, is in my opinion very signifi-



cant and seems to me to exhibit the general tendency of coronal streamers to straighten themselves out at some distance from the sun.

We examined the long streamers on the forty-five second exposure with the 62½-foot focal-length camera to see if one would guess from the shapes of the streamers that there was a violently disturbed region immediately below them. Our conclusions were in the negative, that is, that no one would guess from the shape of the outlying streamer that there was any violent agitation at the solar surface. There are many phenomena that lead one to believe that the corona is a magnetic or electric product and it is possible that it results from a combination of these things. At any rate there seem to be abundant reasons to believe that the problem is not beyond solution.

Dr. L. A. Bauer had consented to give a summary of the magnetic work done during the eclipse of 1918 at stations under his direction. He was prevented from doing this because of his departure to establish stations in Africa and Brazil to make magnetic and electric observations during the eclipse May 29. Before leaving he sent a summary of the chief conclusions that he reached from the observations of the eclipse of June 8, 1918. I shall read this summary.

The following conclusions are drawn covering the chief results of the magnetic observations made in connection with the solar eclipse of June 8, 1918:

(a) Appreciable magnetic effects were observed during the solar eclipse of June 8, 1918, at stations distributed over the entire zone of visibility and immediately outside. (How much further some of the effects may have extended must be left for future study.) The chief characteristics of the effects took place generally in accordance with the local eclipse circumstances and in general accord with effects observed during previous eclipses. The evidences of a direct relation between the magnetic effects and the solar eclipse are so numerous as to warrant drawing the definite conclusion that an appreciable variation in the Earth's magnetic field occurs during a solar eclipse. This particular variation is termed here the "solar-eclipse magnetic variation."

(b) The range of the solar-eclipse magnetic variation, according to the particular magnetic element, is about 0.1 to 0.2 that caused by the solar-diurnal variation on undisturbed days. The effects are of a more or less complicated character, according to location of observation-station in the zone of visibility. The effects caused during the local eclipse-interval are superposed upon those caused by the continued disturbance of the Earth's

magnetic field in the region over which the shadow-cone has already passed. It is thus possible to discern effects having a period approaching that of the local eclipse-interval and others having a period approximately that of the entire or terrestrial eclipse-interval.

(c) The general character of the system causing the solar-eclipse magnetic variation is the reverse of that causing the daylight portion of the solar-diurnal magnetic variation. The range of the eclipse variation is comparable with that of the lunar-diurnal variation, and, like the latter, the variation usually consists of a double oscillation during its period of development.

(d) The range of the apparent effect on the intensity of magnetization of the Earth during the solar-eclipse magnetic variation, is about equal to that found associated with a 10 per cent. change in the solar radiation as shown by changes in the solar-constant values.

(e) The results at the high mountain-station, Corona, Colorado, indicate that the magnetic effects during a solar eclipse may be modified and even intensified by altitude of station, topography and meteorological conditions. In view of the bearing of these results upon the theory of the solar eclipse magnetic variation and possibly upon the theory of other variations of the Earth's magnetic field as well, it will be highly desirable in the planning of future eclipse work to include as many mountain-summit stations as conveniently possible.—*Terrestrial Magnetism*, March, 1919, Vol. XXIV., No. 1.



# RESULTS OF OBSERVATIONS OF THE ECLIPSE BY THE EXPEDITION FROM THE YERKES OBSERVATORY.

By EDWIN B. FROST.

*(Read April 25, 1919.)*

The expedition from the Yerkes Observatory for the observation of the solar eclipse of June 8, 1918, occupied three stations: the principal one at Green River, Wyoming, the second at the Chamberlin Observatory at the University of Denver, and (3) a site near Matheson, Colorado, which had been selected by Professor Barnard and the writer on a reconnaissance trip in 1917.

At the last-named station, Professor Edison Pettit, of Washburn College, Topeka, Kansas, who was at the time an assistant at the Yerkes Observatory, aided by Miss Hannah B. Steele, then fellow in astronomy at the University of Chicago, and by others, obtained some good photographs of the corona with the use of the twelve-inch objective of Washburn College, stopped down to an aperture of four inches, combined with a moving plate according to Schaeberle's method. The first slide shows one of Mr. Pettit's best pictures, with an exposure of one second. The weather was unfavorable in the weeks preceding the eclipse for a considerable extent of the track of totality, but it fortunately cleared at Matheson at the time of the eclipse. Other parties which made successful observations at this station were that of Professor Loud and Mr. Hartley, that from Drake University under Professor Morehouse, and that from the University of Toronto under Professor Chant.

At Denver we received the great courtesy from Director Howe of the use of the twenty-inch Clark equatorial. A special autocollimating spectroscope with a Michelson plane grating belonging to the Yerkes Observatory was adapted in our shops to fit the Denver equatorial. Professor Schlesinger kindly loaned us an attachment from the Porter spectrograph of the Allegheny Observatory

whereby we could bring into juxtaposition images from the east and west limbs of the sun. The scale was about 22 A per mm., and the definition good. The intention was to photograph the green coronal line out to about two minutes of arc from the eastern and western limbs of the sun in order to determine, if possible, the rotation of the corona. With clear weather, we should have had as good a chance of making this test as has been had thus far by other expeditions. The writer spent ten days at Denver getting everything ready, at the end of May, and the observations were to be made by Professor R. S. Nyswander. Unfortunately the day was completely cloudy in the vicinity of Denver.

On the observatory grounds at Denver; we had also installed a small cœlostæt for the direct photography of the corona, utilizing a five-inch objective of twenty-two feet focus, belonging to the Denver equatorial. The installation of this apparatus was attended to by Professor Paul Biefeld, of Denison University, who kindly volunteered his services.

The main station at Green River had also been selected in the previous year, when it was visited by Professor Barnard and the writer on a day of extraordinary atmospheric clearness. The weather records for many years seemed to promise extremely well for this station, although there was much bad weather during the six weeks after our camp was established. The elevation of the station was about 6,200 feet. The day of the eclipse was fine until after noon, when white cumulus clouds began to drift across the sky. A large triangular cloud covered the sun at the time of first contact and moved away with aggravating slowness, so that there was a fair question for twenty minutes previous to totality whether or not the sun would be covered by the cloud. Unfortunately the cloud did not drift away until some three minutes after totality.

Although we had a fine view of the corona and of the brilliant prominences through the edge of the cloud, the spectroscopic observations were very greatly impaired. To me, the visual phenomena of the eclipse were much more impressive than they were in a perfectly clear sky at Wadesboro in 1900.

The direct photographs of the corona and prominences were made under Professor Barnard's direction: (1) with the cœlostæt



and a six-inch objective of sixty-two-feet focus, with the exposures by Miss Mary R. Calvert, who had her station in the dark room; (2) with the twelve-inch Kenwood equatorial of this observatory, operated by Professor Barnard, with several smaller cameras attached to the tube. Professor Barnard makes the following comment on the apparent connection of some of the coronal streamers with prominences:

"APPARENT CONNECTION OF SOME OF THE CORONAL STREAMERS  
WITH PROMINENCES.

"Perhaps no photographs of a previous eclipse have shown with such beauty and distinctness the succession of expanding arches that must have extended above some of the prominences like great spreading envelopes. This is strikingly shown by a large coronal form, made up of numerous arches that seem to center about the remarkable "skeleton" prominence, the position angle of whose base is  $253^{\circ}$ . A similar but smaller form and arches are centered about a small prominence in position angle  $206^{\circ}$ . There are other cases, but the arches are not so well developed.

"The intimate connection of some of the coronal streamers with some of the prominences is best shown by a small prominence in position angle  $234^{\circ}$ , from which a coronal streamer apparently emanates and in which it seems to have its actual origin. Close to this, to the west, is a long, low-lying prominence, in position angle  $240^{\circ}$ , in which similar coronal streams seem to have their origin. Originating apparently in a projection in the southerly part of this prominence, a broad stream bends westward over the entire prominence. From the great prominence in position angle  $298^{\circ}$  there are strips of matter apparently streaming southward toward the equator, as if impelled by some directing force.

"On account of the large scale on which they are taken, these features are shown to good advantage on the photographs with the  $61\frac{1}{2}$ -foot cœlostæt."

It had been my hope that we could apply to the problem of the rotation of the corona the method of the interferometer so successfully used by Messrs. Fabry, Buisson and Bourget in photographing interference fringes in the Orion nebula (*Astrophysical Journal*,

Vol. 40, pp. 241-258, 1914). While this method would be quite difficult of application and there might be a reasonable doubt as to whether sufficient exposure could be given to secure a proper impression of the rings from the green coronal line, nevertheless a successful photograph would be of the greatest value, both for studying internal motions of the corona and its rotation as a whole.

I had the great advantage of discussing this with M. Fabry during his visit to the United States as chairman of the French Scientific Mission. He very kindly offered the loan of the apparatus used at Marseilles, and, if it had arrived in time, we should have tried the method, employing a rather small image of the sun in the hope of getting sufficient intensity. Unfortunately the apparatus did not reach us until long after the eclipse.

I hope that this method will be properly tested at some future eclipse.

The flash spectrum as hitherto photographed has represented a composite of the successive images of the different reversing lines during the critical second or two at second and third contacts. Exceptions to this have been the instances where Professor Campbell has employed a falling plate. I am not sufficiently familiar with the results thus obtained, of which I have not seen reproductions, to know how definitely the different stages of the brief phenomenon are recorded. It seemed to me that the movie camera was at present in a sufficient state of development to be successfully applied to this problem. A "Universal" type of camera was employed, with its short-focus lens removed, and this was attached, without alteration or injury to the machine, to an objective-prism spectroscope having three large Mantois prisms and a special camera lens of 5 cm. aperture and 40 cm. focus. This gave a scale of 13 Å per mm. in the vicinity of  $H\gamma$ . Only a small portion of the spectrum can be photographed with the commercial machine because of the size of the film, which allows an image 1 inch  $\times$   $\frac{3}{4}$  inch (25 mm.  $\times$  18 mm.). A region would naturally be selected in which important lines occurred, or such as it was desired to study particularly. The correct exposure was naturally a question of some uncertainty in advance of the event. This is, of course, determined by the rate at which the crank of the machine is turned. It is arranged for eight



pictures per turn, and after some preliminary experiments, I decided that it was safe to have the crank operated at the rate of two turns per second, giving sixteen pictures per second. Inasmuch as about half of the time was used in moving the film between exposures, this would represent about  $\frac{1}{20}$  of a second for the exposure. On account of the clouds still lingering over the sun, it was not possible to obtain satisfactory pictures at the beginning and end of totality for bringing out the delicate details of the flash. But it is perfectly evident from the pictures that an excellent record of the successive stages of the development of the flash would have been obtained if the sky had been clear. This slide shows a few of the pictures taken several seconds after totality; it will be possible to notice the tips of bright gamma still reversed. The next slide shows a few of the exposures, successively of the 15th, 18th and 23d seconds after totality. Over 2,000 impressions of the spectrum were obtained.

Another and important advantage of this method is that it removes all the uncertainty of making the exposure at the correct instant to secure the flash. This has been a matter of difficulty and consequent nervousness on the part of the observers, even if the signal should be given by a person observing the flash itself visually. By beginning to operate the machine half a minute before the expected time of totality, and running it for a few seconds after totality has begun, there could be no doubt about catching the phenomenon at all the stages and hence precisely at the best instant. Thus the history of the reversal of each line should be shown, and it would be very different for those of high level and those of low level. This could be demonstrated to an audience or to a class by the use of the film itself, and the film of course could be measured as well as an ordinary photographic plate.

It is very easy to connect a chronometer with the machine so as to impress a dot on the film every second or half second, so that the precise instant of each exposure can be known. At Green River, Mr. Blakslee of our staff operated the crank and he was to receive the signal from me as I watched the spectrum with a spectroscope for this purpose. However, I decided during the partial phase that it would be safer to begin the exposure one minute before the predicted time of totality. As a matter of fact, owing to the cloud, I

was unable to see the flash spectrum at the beginning of totality and could see the reversal of but few lines at the end of totality.

It would also be perfectly feasible to operate the film by a direct connection with a chronograph, controlled by a conical pendulum; or, if desired, a graduated change in rate of rotation could be given so that a longer exposure would result before totality (say, an exposure of  $\frac{1}{20}$  second) and a still shorter (say,  $\frac{1}{50}$  second), thirty seconds before and after the contacts. I sincerely hope that this simple method will be included in the plans for the next eclipse expedition, because with clear weather it practically guarantees good results.

I may say here that it is unfortunate that better records of the eclipse were not obtained with movie machines. So far as I have learned no first-class picture was obtained. I took pains to notify some of the film companies, explaining how important it was that they should not depend upon their usual short-focus lenses (two to three inches), but that they should use lenses of at least twenty or thirty inches focus. Some commercial operators at Denver were prepared to do this, and doubtless would have obtained results both instructive and interesting if the weather had permitted.

Our program also included the photography of the infra-red region of the spectrum, with the use of films stained with dicyanin, in connection with a small concave grating of sixty inches focus, used directly. This was the instrument I had employed at Wadsworth in 1900. It was operated by Professor S. B. Barrett, but no results in the infra-red could be obtained through the cloud. It might be a question whether there would be ordinarily time enough for sufficient exposure for the infra-red, and probably future plans in this direction should insure an abundant light-power in the spectroscope.

In connection with the apparatus arranged by Professor Parkhurst for the photometric study of the corona was a reflecting telescope of six inches aperture and sixty inches focus, covered by a  $15^\circ$  prism of ultra-violet glass of the same aperture. One of the exposures made with this instrument is shown herewith, as it brings out an interesting point with respect to the large prominence in position angle  $253^\circ$ , already shown from Professor Barnard's negative



and designated by some as the "heliosaurus." As may be seen from the slide, the prominence is visible only in the *H* and *K* lines of calcium. If present at all in the other emissions it is too weak to impress the plate. On the contrary, the quiet prominence at position angle  $297^\circ$  (=north latitude  $40^\circ$ ) appears also in the *H $\beta$* , *H $\gamma$* , and *H $\delta$*  lines, and the prominence at position angle  $51^\circ$  (=north latitude  $26^\circ$ ) is bright in helium *D $_3$*  as well as in the hydrogen series.

The low prominence or uncovered photosphere at position angle  $240^\circ$  (=south latitude  $17^\circ$ ) shows a remarkable extension into the ultra-violet, the bright group between wave-lengths 3350 and 3390 Å being especially strong. This prominence is an origin of coronal streamers, as Professor Barnard has shown in his paper on page 223.

The continuous spectrum of the corona is so strong that it masks the narrow rings due to the bright coronal lines at wave-lengths 5303, 4231 and others.

YERKES OBSERVATORY,  
April 18, 1919.

## THE BASIS OF SEX INHERITANCE IN SPHÆROCARPOS.

By CHARLES E. ALLEN.

(Read April 25, 1919.)

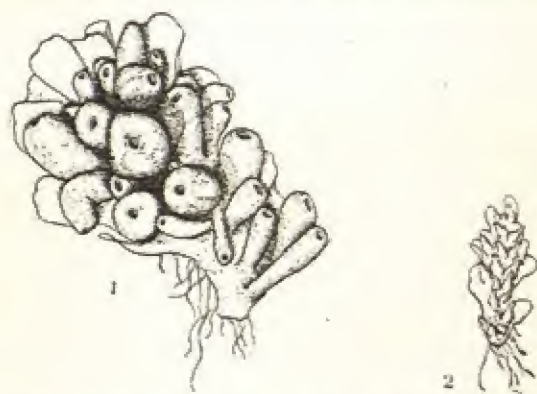
### SPHÆROCARPOS IN CULTIVATION.

The studies here described were made upon cultures of *Sphaerocarpos Donnellii* Aust. growing under greenhouse conditions. Through the kindness of Dr. A. B. Stout, living plants of this species were received from the New York Botanical Garden on January 13, 1916. These plants, as Dr. Stout informed me, had been obtained from Mr. Severin Rapp, Sanford, Florida. To a request for additional material Mr. Rapp very generously responded, as he has to later similar requests, and the greater part of my present cultures of this species began with material which he sent. Plants have been received from Mr. Rapp on February 4 and March 10, 1916, on January 21 and February 23, 1918, and on April 10, 1919. On February 16, 1916, plants of *Sphaerocarpos* were obtained for class use from the Plant Study Company, Cambridge, Massachusetts. A letter from the company informed me that they had been collected at Miami, Florida, by Miss Clara Hart. Some of these plants were used also as starting points for greenhouse cultures. Plants of all the cultures here referred to have been identified as those of *S. Donnellii*, and this identification has been confirmed by Miss Caroline C. Haynes, to whom were sent representatives (including sporophytes) of each set of cultures except those derived from the last lot of plants supplied by Mr. Rapp.

My experience has shown that the thalli of *S. Donnellii* (and of *S. texanus* Aust. as well) can be kept growing indefinitely, the posterior portions dying as growth continues at the anterior end. This applies to the gametophytes of both sexes, although the male thalli are much more susceptible to unfavorable conditions and it is only with some care and difficulty that cultures of the male plants can be



kept in healthy condition. In mixed cultures the female plants crowd and choke out the males, which latter in such cultures are sure sooner or later to disappear. As already indicated, I have cultures (now purely female) which have been growing continuously since the early months of 1916, the plants having multiplied as a result of their branching and apical growth and of the death of the older portions, as well as by regeneration which occurs freely under a variety of conditions from the lateral lobes, from the body of the thallus, and from the involucre. Sporophytes have been formed and the spores scattered in some of the cultures, in which cultures therefore not all the individuals now living are the result of the vegetative growth of those originally present. It is easy, however, to obviate this possibility, so that a culture (clon or pure line) of any desired extent can be obtained which is known to have been derived by vegetative means from a single gametophyte, or from



*Spharocarpus Donnellii*. Living female (FIG. 1) and male (FIG. 2) plants. Received from Sanford, Florida, April 10, 1919; drawn April 15, 1919. A very small portion of the anterior end of each plant (the upper ends in the figures) represents growth since transference to the greenhouse; otherwise the plants are typical of those in nature. Drawings by Miss Martha Engel.  $\times 7$ .

the germination of a single spore. My oldest male cultures date from spores which were sown June 16, 1916, the plants derived from which were transplanted and have been kept in culture since March 10, 1917.

C. and R. Douin (1917) report having kept female plants of *S. terrestris* (= *S. Michellii* Bell.) and *S. californicus* (= *S. texanus* Aust.) in cultivation for nine or ten months, and conclude that the female thalli "may live indefinitely at a suitable humidity." The male thalli, however, they say, are much less resistant and "disappear little by little in the presence of humidity." Campbell (1896) has noted the appearance of *Sphærocarpos* plants (apparently of both sexes) in a culture of other liverworts grown under glass, and Goebel (1907) describes a culture of female plants which had grown vigorously for two years. So far as I know, these are the only previously published accounts of *Sphærocarpos* in culture.

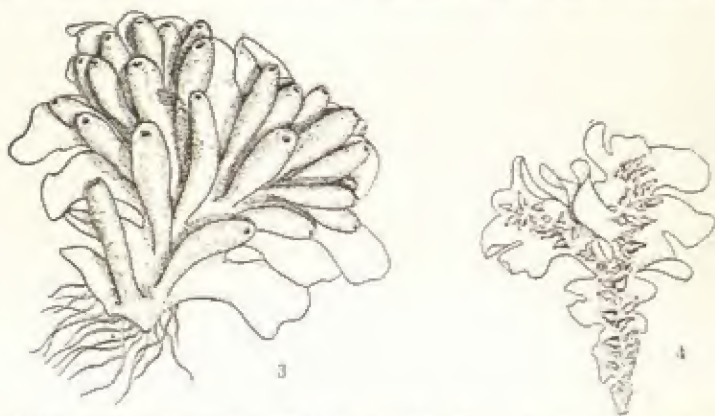
In my own work, best results have been obtained by growing the plants in pots containing a mixture of about equal parts of clay loam and sand. The pots stand on earthenware plates or enameled metal pans in a Wardian case; a little water is kept in the plates or pans. The soil in the pots is thus constantly moistened from below. Under these conditions contamination of the cultures by other organisms is kept at a minimum, though of course by no means entirely prevented; and, even in case plants of both sexes are growing in the same pot, fertilization does not occur. Fertilization can be brought about when desired by flooding from above with sterilized water a pot containing male and female thalli. The plants must be transplanted occasionally, both to relieve overcrowding and to free the cultures from contamination, especially by blue-green algæ, which are the greatest source of trouble. The only other weeds that cause serious annoyance are mosses, and they are not difficult of exclusion when a culture is once free from them.

Campbell (1896) and C. and R. Douin (1917) have noted that *Sphærocarpos* under greenhouse conditions takes on a form noticeably different from that which it exhibits in nature. Campbell's plants were either (or both) those of *S. californicus* Aust., which Miss Haynes (1910) and the Douins agree is identical with *S. texanus* Aust., or of *S. cristatus*, a California species later separated and described by Howe (1899). The Douins' statements apply to both *S. Michellii* Bell. and *S. texanus*.

The observations of these authors are confirmed by my own on *S. Donnellii*. Figs. 1 and 2 represent female and male plants, re-



spectively, drawn (living) a few days after their receipt from their native habitat (Sanford, Florida), and therefore fairly typical of the wild form. The female and male plants shown in Figs. 3 and 4 were taken from greenhouse cultures nearly three years old. The most conspicuous differences result from the fact that the plants of both sexes, and particularly their vegetative parts, grow more rap-

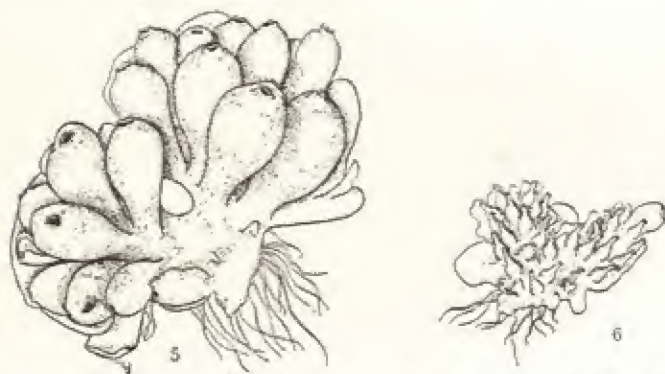


*Sphærocarpos Donnellii*. Living female (FIG. 3) and male (FIG. 4) plants from greenhouse cultures. Rhizoids not shown in Fig. 4. Drawings by Miss Martha Engel.  $\times 7$ .

idly and more luxuriantly under favorable conditions indoors; the branching is thus more noticeable, and the lateral lobes especially, which in the wild plants are ordinarily insignificant, become, as previous observers have noted, decidedly leaf-like. The involucre surrounding the sex organs become slenderer and often longer, the archegonial involucres being characteristically tubular in the greenhouse form. The orifices of the archegonial involucres are frequently quite wide in plants grown in the greenhouse, though this was not true of most of the involucres of the particular plant shown in Fig. 3. As a result of the greater development of the vegetative parts and the lessened diameter of the involucres, the latter (in both male and female) appear less crowded in the cultivated than in the wild form. Similar modifications appear in cultures of *S. texanus*, as is shown by a comparison of Figs. 5 and 6 (wild form) with Figs. 7 and 8 (greenhouse form). The plants shown in Figs. 5

and 6 were sent from Austin, Texas, by Professor F. McAllister; those shown in Figs. 7 and 8 were from cultures which began with plants received from Professor R. S. Cocks, New Orleans, January 15, 1917, the drawings having been made in February, 1919.

It must be noted, in considering the differences in question, that



*Sphærocarpos texanus*. Living female (FIG. 5) and male (FIG. 6) plants as found in nature. Received from Austin, Texas, February 13, 1919; drawn February 15, 1919. Drawings by Miss Martha Engel.  $\times 7$ .

in such characters as the size and form of the lateral lobes, size, form, and closeness or distance apart of the involucre, and size of orifice, there is great variation between individual plants in the cultures, as well as evidently also in nature. Compare, for example, Figs. 3 and 9, both representing female plants of *S. Donnellii* from greenhouse cultures, that shown in Fig. 9 bearing sporophytes. Much of this variation is obviously due to environmental conditions, but some of it apparently to the existence of differing strains of sub-specific rank.

The changes that appear under cultivation seem not to be correlated with any loss of function on the part of the sex organs or of the gametes. At any rate, it is easy, as already noted, to secure fertilization, as a result of which sporophytes are formed in abundance, especially in late winter and spring. At other seasons either fertilization or sporophytic development seems to meet with more difficulty, and the proportion of sporophytes obtained is ordinarily smaller.



The sporophytes appearing in the cultures have given rise to spores which were apparently normal in every respect and which germinated, although thus far there has always been a considerable proportion of ungerminated spores. Whether this failure of some of the spores to germinate is due to a lack of viability or to a failure to provide the most favorable conditions for germination is a question yet to be determined. The spores of *S. Donnellii* in my cul-



*Sphaerocarpos texanus*. Living female (FIG. 7) and male (FIG. 8) plants from greenhouse cultures. Rhizoids not shown. Drawings by Miss Martha Engel.  $\times 7$ .

tures invariably remain united in tetrads (FIG. 11), even to a time when the capsule wall, calyptra, and surrounding involucre have completely broken down and the spores consequently are being scattered.<sup>1</sup> Such a persistent union of the spores is characteristic, as is well known, of other species of *Sphaerocarpos*, but not, according to Miss Haynes (1910), of *S. Donnellii* as found in nature.

#### THE SEX RATIO IN SPHÆROCARPOS.

C. Douin (1909) investigated the sex of the respective members of groups of the thalli of *Sphaerocarpos*, the members of each group having resulted presumably from the germination of the spores of a tetrad. His observations showed that, at least as a general rule,

<sup>1</sup> Since this was written, it has been observed in one culture, containing numerous sporophytes, that the tetrad walls had largely broken down, allowing the spores to become separated from one another.

two of the four spores of a tetrad develop into female plants and the other two into male plants. In 9 cases of 81 studied, more than four plants were present in a single group; but on the assumption that two tetrads had germinated in close proximity, these cases were brought into harmony with the rule. In only four instances of the 81 the distribution of sexes was "abnormal" (5 females and 3 males, 1 female and 3 males, and in two cases 3 females and 1 male). The plants thus studied by Douin apparently included representatives of both *S. Michellii* and *S. texanus*. The evidence thus furnished was cited by Strasburger (1909) as proof that in *Sphero-*



FIG. 9. A female plant of *Spharocarpus Donnellii* from a greenhouse culture; sporophytes are present within the swollen bases of several of the involucre, as at *s, s*,  $\times 7$ . FIG. 10. A portion of a similar plant in vertical section showing the relation of the sporophytes (*s, s*) to the structures of the gametophyte.  $\times 7$ . FIG. 11. A group of four spores, resulting from the division of a single spore mother cell and remaining permanently attached.  $\times 312$ . Drawings by Miss Martha Engel.

*carpos* the sex tendencies, brought together in the union of egg and antherozoid and remaining united, though of course not finding expression, during the life of the sporophyte, are separated by the



reduction divisions which result in the formation of four spores from each spore mother cell—a notion strongly suggested by previous investigations of dioecious liverworts and mosses.

Spores being available in considerable numbers in my cultures, it seemed worth while to attempt to determine whether the conclusions thus arrived at for the European species hold likewise for *S. Donnellii*. Spores liberated by breaking the capsule wall in a drop of water were sown on soil June 16, 1916. Spores sown at this time of year have been found to be relatively slow in germination; the sporlings appeared during the following autumn and winter. On March 10, 1917, most of the plants that resulted having begun to produce involucre, those that had grown from the spores from two capsules were carefully examined, with the results shown in Table I. As a rule, plants of a group of four could be reason-

TABLE I.

SEX OF PLANTS GROWN FROM SPORES FROM TWO CAPSULES OF  
*Sphærocarpos Donnellii* (CULTURE PSC<sub>2</sub>B).

Spore tetrads sown June 16, 1916; plants examined March 10, 1917.

2 females, 2 males	3 groups
2 females, 1 male	2 groups
1 female, 2 males	1 group
1 female, 1 male	1 group
2 females,	1 group
2 males	3 groups
1 female,	1 group
1 male	1 group
1 female, 2 males, 1 ?	3 groups
2 ?	1 group
4 ?	1 group
3 females, 1 male,	1 group
4 females, 2 males,	1 group
2 females, 3 males, 2 ?	1 group
3 females, 2 males, 3 ?	1 group

Totals: 30 females, 32 males, 14 (?).

ably assumed, because of their contiguity, to have come from the spores of a single tetrad. Sometimes, however, the plants in a group were sufficiently separated to make their relationship, though probable, open to question. Isolated plants, or groups of two or three, evidently indicated that one or more spores had failed to

germinate, or that the sporelings growing from them had died. A question mark (?) in the table indicates that no involucres had yet appeared upon the plant in question, so that its sex could not be determined.

It is plain that all the cases shown in Table I., with the exception of the last four, harmonize with the expectation of two females and two males. The last three cases can be made to harmonize by the assumption made by Douin, namely, that two spore tetrads germinating in close proximity may give rise to a group of eight plants (or fewer), which will be expected to include four females and four males. There remains one case (of three females and one male) which does not agree with the expectation, unless it be assumed to represent the four survivors of a group of eight.

However, it appeared from this study, as well as from a more extended observation of the behavior of plants in culture, that the question of the sex potentialities borne by the spores can be finally settled only by the use of more exact methods. The sources of possible error are at least three: the impossibility of determining with certainty just which plants have come from the spores of a single tetrad; the multiplication of plants as a result of their branching and the separation of the branches as independent plants, either by accident or by the death of the older portions; and the production of new plants by regeneration. All these sources of error are likewise present in the observation of plants growing in nature, although the second is perhaps less important under these conditions because of the slower growth out of doors. It is thus quite possible that Douin's "abnormal" cases may not be real exceptions to the general rule; although, on the other hand, it must be admitted as at least conceivable that in an occasional instance an error from one of the causes mentioned might make a really aberrant case seem to agree with the rule. The possibility of a modification of the apparent sex ratio as a result of branching or of regeneration has recently been recognized by Douin (C. and R. Douin, 1917).

Attempts to develop better methods of studying this question led to the sowing of isolated tetrads on various substrata. Difficulties have been met with in securing favorable conditions for germination and in preventing contamination, and the results thus



far are small. In one culture, however, a sufficient number of germinations were obtained to make the results of some value (Table II.). In this case 24 tetrads, all from a single capsule, were sown on filter paper which was moistened with a nutrient solution made according to the formula given by É. and É. Marchal (1907),

TABLE II.

SEX OF PLANTS DERIVED FROM SPORES FROM ONE CAPSULE OF  
*Spharocarpus Donnellii* (CULTURE R19).

Spore tetrads sown separately on moistened filter paper March 17, 1917;  
sporelings separated and removed to pots of soil May 25 to June 1, 1917.

2 females, 2 males	1 group
2 females, 1 male	2 groups
1 female, 2 males	1 group
1 female, 1 male	1 group
2 females,	1 group
1 female,	1 group
1 male	1 group
1 female, 1 male, 1 ?	1 group
1 female, 2 ?	2 groups
1 female, 1 ?	1 group
2 males, 1 ?	1 group
1 male, 1 ?	3 groups
2 ?	1 group

Totals: 15 females, 14 males, 12 (?).

placed in a petri dish, and sterilized before the spores were sown. The sporelings were removed from the filter paper while they were still very small and while their attachment to the spore wall could still be distinguished; there could thus be no question as to the origin of the plants of a group, and their youth precluded the possibility of a previous multiplication by vegetative means. The sex of the plants was determined, so far as this could be done, at the time of their removal from the filter paper, and each was transplanted to a separate pot of soil. In the cases in which the plants continued to live after transplanting, observations as to their sex were made after further development. Some of the plants died after transplanting and before producing involucre, and these are the ones whose sex is indicated as doubtful in the table.

Although more extended observations are desirable, it seems

quite clear from these results that the general conclusion arrived at by Douin and Strasburger for the species of *Sphaerocarpos* considered by them applies also to *S. Donnellii*—namely, that the differences which distinguish female from male plants result from differences in the spores that are to give rise to them, and that of the spores formed by the division of a single mother cell two bear female potentialities only and two male potentialities only. It seems probable, too, that exceptions to this rule, if any occur, are less frequent than might be thought from Douin's observations—his apparently aberrant cases probably having resulted from some of the causes of error already noted. It is not intended to be suggested, however, that positive exceptions to the rule will not be found. The possibility of such exceptions will be discussed on a later page. The occurrence or non-occurrence of an exceptional distribution of sex characteristics, and the proportion of such occurrences, if any, are evidently to be determined by the observation of thousands of plants rather than of a few score.

It will be noticed from Tables I. and II. that the number of plants certainly referable to the respective sexes is substantially equal: in the one case 30 females and 32 males, in the other 15 females and 14 males. Thus it appears that so far as power of germination is concerned there is no marked difference between female-producing and male-producing spores. This fact is striking in view of the great difference in favor of the female plants in rate of growth and in power of resistance to unfavorable conditions. Apparently this difference, which for want of a better word may be spoken of as one of "vigor," does not exist, or at least come to expression, as between the spores, but becomes apparent at some time after germination and during the development of the gametophytes.

While there seems to be no difference between the female- and male-producing spores in their capacity for germination, it remains possible that there is a difference in time or rate of germination. On this question the foregoing observations throw no light, but a suggestion is furnished by a recent set of experiments in which an attempt has been made to study this particular point. On December 27 and 28, 1918, 67 tetrads from two capsules were sown in as many pots of soil, one tetrad to a pot. Germination has been slow, and



additional sporelings are still occasionally appearing. However, the slowness of germination has given opportunity for the entrance of blue-green algæ, whose presence in quantity either checks further germination or results in the death of the young sporelings while very minute. The germinations observed in this series have resulted as follows:

In 12 pots, 1 female sporeling;

In 4 pots, 1 male sporeling;

In 1 pot, 1 of undetermined sex;

In 1 pot, 1 female followed by 1 female;

In 1 pot, 1 male followed by one male, and this by one of undetermined sex (the latter possibly, though apparently not, a regenerated shoot);

In 1 pot, 2 males appearing nearly or quite simultaneously;

In 1 pot, 1 female followed by 2 of undetermined sex.

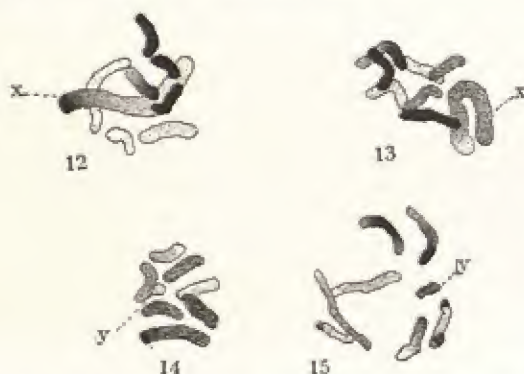
Thus in 14 cases a female-producing spore seems to have been first to germinate; in 6 cases, a male-producing spore. While too fragmentary to furnish a basis for a conclusion, these figures suggest that there may be a difference in rate of germination in favor of the female-producing spores.

#### THE CHROMOSOMES OF SPHÆROCARPOS.

*Sphaerocarpos* suggested itself as a favorable plant in which to look for a possible chromosome difference between the sexes, both because of its marked sexual dimorphism and because of the strong evidence of a relation between chromosome reduction and the separation of sex potentialities. So far as published records show, the only previous attempt to study the chromosomes of *Sphaerocarpos* was by Strasburger (1909), who reports that neither in the nuclear divisions in the spore mother cell nor in the structure of the nuclei formed by these divisions did he find any evidence of the separation of structures that could be interpreted as the bases of sex differentiation.

In April, 1914, through the courtesy of Professor Mangin and of M. Capus of the Muséum d'histoire naturelle of Paris, I was enabled to locate living plants of *Sphaerocarpos* (probably of *S. Micheli*) in the neighborhood of Bois-le-Roi. Some of this mate-

rial was fixed and studied in Professor Mangin's laboratory. The amount available was too small and the stage of development for the most part too advanced to furnish definite results; but it gave an opportunity for acquiring a familiarity with the plants and for testing methods of fixation. When greenhouse cultures of *S. Don-*



FIGS. 12 AND 13. Chromosome groups from female gametophytes of *Spharocarpus Donnellii*: Fig. 12, from a basal cell of an archegone; Fig. 13, from the basal part of a young archegonial involucre; *x*, the large chromosome. FIGS. 14 AND 15. Chromosome groups from male gametophytes of *S. Donnellii*: Fig. 14, from the wall of a young antherid; Fig. 15, from a projecting superficial cell of the apical meristem, possibly an antheridial initial; *y*, the small chromosome.  $\times 3800$ .

*nellii* were later obtained in vigorous condition, the cytological study was renewed. Some of the results of this study have already been briefly reported (Allen, 1917*b*).

Figs. 12 and 13 show typical chromosome groups from cells of the female gametophyte; Figs. 14 and 15, corresponding groups from cells of the male gametophyte. In each case, as the figures show, eight chromosomes are present. In the female, one of the eight chromosomes (*x*, Figs. 12, 13) is much longer and thicker than any of the others. The other seven differ in length among themselves. It is probable that all the individual chromosomes of different cells can be identified by their length; but since in sections the chromosomes lie at various angles and thus some of them are always foreshortened in the camera lucida drawings, it will require the assembling and study of a considerable number of figures showing



the chromosomes in favorable positions to make such identification reasonably certain. However, in all of the numerous division figures that have been seen in various parts of female plants the single large chromosome is present and conspicuous.

The chromosome groups of the male contain no element at all like the large chromosome of the female. Seven of the chromosomes of the male, varying in length among themselves, seem to correspond to the seven smaller ones of the female. The eighth chro-

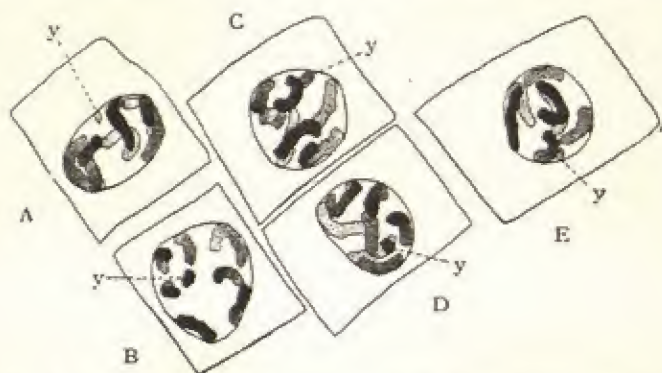
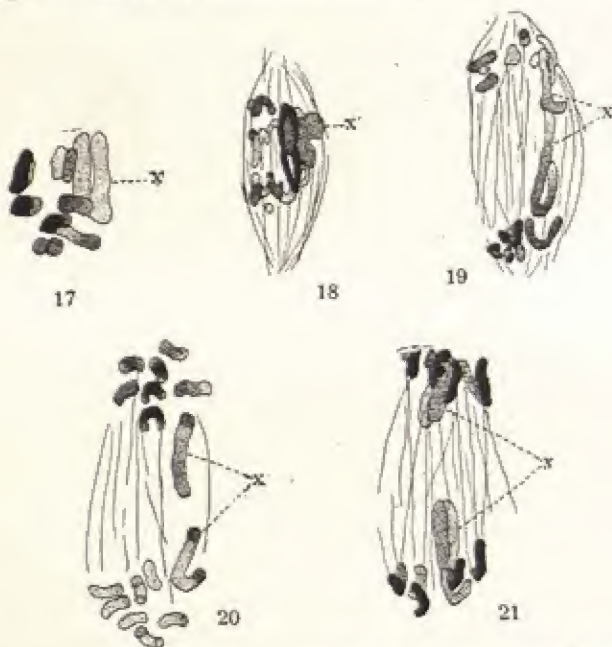


FIG. 16. A group of cells from a developing antheridium; nuclei in late prophase; y, y, the small chromosome.  $\times 3800$ .

mosome (y, Figs. 14, 15, 16) is very small. This small chromosome is not always easily distinguishable. In the group shown in Fig. 14, for instance, the body y is very lightly stained; the same is true of the body similarly identified in cell A, Fig. 16. However, in the majority of cases, as in cells B, C, D, and E, Fig. 16, and in the cell shown in Fig. 15, in which the chromosomes are unusually widely scattered, this small element is stained like the other chromosomes and is plainly one of them. It appears certain, therefore, that a very small chromosome in the male in some way corresponds to, or replaces, the very large one of the female.

Figs. 17 to 21 show stages in the division and separation of the chromosomes in dividing cells of the female. In the cell represented in Fig. 17 the chromosomes or most of them, including the large one, are longitudinally split. Figs. 18 to 20 illustrate a peculiarity in the behavior of the large chromosome—namely, that its daughter

halves are the last to separate in the metaphases (Fig. 18), and that they lag behind the other daughter chromosomes in their passage to the poles of the spindle (Figs. 19, 20). Even at the late stage shown in Fig. 21, the large daughter chromosome moving toward the lower pole of the figure is still a little in the rear of its fellows, which have reached the spindle pole. In this respect the behavior of the large chromosome recalls that of the X-chromosome in the heterotypic divisions of certain insects, and in some cases at least



FIGS. 17-21. Stages in nuclear division in the female gametophyte: Fig. 17, a late prophase, the chromosomes showing longitudinal splitting, in a cell of the calyptra; Fig. 18, a metaphase in an involucre cell; Fig. 19, an anaphase in an involucre cell; Fig. 20, a later anaphase in a young thallus lobe; Fig. 21, a diaster in a cell at the base of a young lobe; *x*, the large chromosome.  $\times 3800$ .

in the homœotypic divisions of these animals as well. It is quite possible, to be sure, that this lagging of the large chromosome of *Sphærocarpos* is merely a result of its proportionately great size.

Relatively few division figures have been observed as yet in the



developing sporophyte. Those which have been seen show that about sixteen chromosomes are present and that one and only one of the group is much larger than the others, being, therefore, obviously derived from the female parent. Fig. 22 represents the two anaphase groups in a dividing cell of a young sporophyte; each group shows fifteen chromosomes, one of which is the large one. The sixteenth chromosome which would be expected to appear in



FIG. 22. Two anaphase chromosome groups in a dividing cell of a young sporophyte; *A*, the group seen at an upper, *B*, that seen at a lower, focus; *x*, the large chromosome.  $\times 3800$ .

each of these groups is, it seems likely, the small element derived from the male parent, which here is not seen either because of its too light stain or because it is hidden by one of the others.

The first division of the spore mother cell nucleus (the heterotypic division) has not yet been seen; but a considerable number of spore mother cells have been found in which the second (homöotypic) division was in progress. In every one of these latter cases in which the complete series of sections of a spore mother cell was present, one of the two spindles in the cell bore a large chromosome, and the other did not. Figs. 23 and 24 show polar views of the two homöotypic metaphase groups in a single spore mother cell; in the group of Fig. 24 a large chromosome (apparently longitudinally split) is present; the group of Fig. 23 includes no large chromosome. An exact count of the smaller chromosomes has not been found possible at this stage because of the irregularities in their shape and distribution. The fact that a single group is commonly represented in several sections (those chosen for Figs. 23 and 24 are unusually favorable in this respect) involves additional difficulties.

The conclusion seems warranted, from the presence of a large

chromosome on only one of the two homœotypic spindles in a spore mother cell, that in the heterotypic division the large and small chromosomes pass respectively to different daughter nuclei. This means that the separation of these two very different bodies is effected in the same division as that which, on the basis of the best cytological evidence, seems to result in the qualitative separation of other ("ordinary") chromosomes. It remains to determine from a study of the heterotypic division just how this separation is brought about.



FIGS. 23 AND 24. The two chromosome groups, seen in polar view, in a metaphase stage of the homœotypic division in a spore mother cell. The great majority of the chromosomes on the two spindles (shown in Figs. 23B and 24A) were in the same section; Fig. 23A shows a single chromosome belonging to the group of Fig. 23B, appearing in the previous section; and Fig. 24B, two chromosomes (or a dividing chromosome) belonging to the group of Fig. 24A, and appearing in the following section; x, the large chromosome.  $\times 3800$ .

Of the four nuclei formed in the spore mother cell, two sister nuclei, and therefore the two spores into which these nuclei pass, receive a large chromosome each; the other two nuclei (and spores) receive a small chromosome each. Since the large chromosome is always present in the cells of the female and never in those of the male, it follows that a spore receiving a large chromosome must develop, if it develops at all, into a female gametophyte, and that a spore receiving a small chromosome must develop, if it develops at all, into a male gametophyte.

#### THE CHROMOSOMES AND SEX CHARACTERS.

What I have hitherto referred to respectively as the "large" and the "small" chromosome of *Spharocarpus* are so closely similar in appearance and behavior to the sex chromosomes of various



animals—especially of such insects as *Lygaeus* and *Euschistus* (Wilson, 1906, 1912; Montgomery, 1911)—that in the remainder of the present discussion they will be designated, as commonly are the apparently corresponding bodies in animals, the “X-” (large) and “Y-” (small) chromosomes. This terminology is borrowed for the sake of simplicity, in spite of the fact that it may require revision in the light of future investigations.

Whatever may later appear in this respect, at present the problem of the relation of the X- and Y-chromosomes to the complexes of characters that distinguish male from female seems to be similar in its broadest terms in *Sphaerocarpus* and in those animals whose possession of sex chromosomes has been demonstrated. The suggestion of an underlying similarity, however, does not involve maintaining that the precise relation of these particular chromosomes to certain hypothetical sex-determining factors is identical in all organisms in which X- and Y-chromosomes are found. Indeed, there appear at present to be, as regards the relation between special chromosomes and characters distinctive of sex, three quite different types of cases:

(a) Those in which, in terms of the chromosomes, the female is homozygous because it possesses what Wilson (1909) has called two “X-elements”—the X-element in different instances being a chromosome or a group of chromosomes; and the male heterozygous because it possesses either one X-element only, or one X- and one Y-element; the Y-element, if present, sometimes consisting of one body, sometimes of a group. To this class are now referable a large number of animals representing several phyla.

(b) Those in which the male is homozygous, possessing two X-elements, and the female heterozygous, possessing one X-element only, or one X- and one Y-element. This class, apparently smaller than the first, is established upon the basis of suggestive cytological observations which in no case as yet cover the whole life history, and of a larger amount of evidence derived from experimental breeding.

(c) Those in which the female possesses one X-element (or chromosome), the male one Y-element, and in which the diploid generation (the sporophyte) is heterozygous in terms of the chro-

mosomes although phenotypically asexual. To this class can be assigned at present with certainty only two species of *Sphærocarpos*: *S. Donnellii*, discussed in the present paper, and *S. texanus*, in which Miss Schacke (1919) has recently found a condition as to chromosomes similar to that in *S. Donnellii*. It may be hazarded, however, that here belong also the dioecious mosses upon which the epoch-making studies of the Marchals (1907, 1909, 1911) were made; the heterozygous sporophytes of these mosses were induced to give rise by regeneration to diploid and hermaphroditic gametophytes.

The differences in the apparent relations of the chromosomes in question in the organisms representing these three classes are brought out strikingly by the facts that in class *a* two X-elements are necessary to the appearance of femaleness, but only one X-element (with or without a Y-element) to that of maleness; that in class *b*, two X-elements are requisite to the appearance of maleness, and only one X-element (with or without a Y-element) to that of femaleness; whereas in class *c* the presence of one X-element means femaleness, that of one Y-element maleness, and the presence of both, under ordinary conditions, is correlated with non-sexuality.

Another difference, at least as between the plants of class *c* on the one hand and the animals of class *a* on the other, lies in the apparent lack of function in heredity of the Y-chromosome or -element in animals, as shown by its utter absence in many forms and by the genetic evidence of its failure when present to influence the transmission of sex-linked characters; although Bridges' (1916) evidence in this connection should be cited, namely, that the absence of the Y-chromosome in *Drosophila*, while not affecting the apparently normal development of the male animal, does result in sterility. In *Sphærocarpos*, however, there is no reason at present for considering the Y-chromosome to be in any sense a functionless body. Its presence seems, as will be indicated more fully in a later paragraph, to be related to the appearance of definite characters in just as positive a way as is the presence of the X-chromosome. And in the normally dioecious mosses studied by the Marchals, heterozygosis in the diploid gametophyte manifested itself by the appearance of both male and female characters.



The visible differences between male and female plants of *Sphærocarpos* fall naturally into two categories:

(a) Differences in rate of growth and in the size at maturity of homologous parts (compare, for example, Figs. 1 and 2, or 3 and 4), and, probably intimately connected with these, a difference in power of resistance to unfavorable conditions; in each of these respects the advantage is with the female.

(b) Differences in form and structure of the sex organs (antheridia and archegonia), and of course of the gametes themselves, as well as in the form and structure of the involucre surrounding the sex organs. These differences in structure are associated with size differences—for example, the archegonial involucre is much larger than the antheridial involucre, as well as different in form—but it does not follow that characters of size and those of form, though constantly associated and even causally related, have been brought to expression by the same chain of causative factors.

Of none of these distinctive characters, it may be noted, is there any apparent reason for suspecting that it has anything in common with the "secondary sexual characters" of the higher animals.

That the possession by each sex of its own complex of distinctive characters—hereinafter referred to for the sake of brevity as "sex characters"—constituting a constant phenotypic difference between the sexes, is the expression of a genotypic difference, can hardly, I think, be doubted; for all the available evidence indicates that *Sphærocarpos* is strictly and under all circumstances dioecious, and that an individual gametophyte possesses one and only one set of potentialities so far as sex characters are concerned. This being the assumption upon which discussion must for the present rest, it follows that the respective groups of sex characters (or their physical bases) are separately inherited by the sexual from the asexual generation through the spores, which latter are the only possible vehicle of transmission from sporophyte to gametophyte. Since two spores of each tetrad develop into plants of either sex, the conclusion already drawn by previous writers seems inevitable, namely, that the physical bases for the sex potentialities were united in the sporophyte down to the time of the formation of the spore mother cells, and that the separation of these physical bases occurred in the

course of the divisions which formed the spores. The invariable connection of the X-chromosome with femaleness and of the Y-chromosome with maleness seems to prove a causal relation of some sort between the presence of either chromosome and the appearance of the characters of the corresponding sex. The further logical step seems likewise inevitable, although admittedly it raises questions of considerable difficulty—the conclusion, namely, that it is the presence of an X- or of a Y-chromosome in the cells of a particular plant which determines the appearance in that plant of the characters of the corresponding sex. This essentially corresponds with the hypothesis which the students of the sex chromosomes of animals seem in general to have adopted—although naturally the form of the statement, as of the precise fact, is different for an organism whose sexual generation is diploid rather than haploid.

The facts in the life of *Sphaerocarpus* that seem to force this conclusion upon us are, first, that, as already noted, the physical bases for the sex characters must have been separated in the course of the divisions in the spore mother cell and distributed among the four resultant spores; and second, that the only structures that are shown to have been so separated and distributed are the X- and Y-chromosomes—the four spores being to all appearances alike in all other points of structure, form, and size. The difficulty of imagining how the sex chromosomes can function in impressing sex characters upon the plant—a difficulty which, however, is but of the same order as that which confronts the very widely accepted theory of the function of the chromosomes in inheritance in general—will continue to breed a healthy skepticism and will stimulate the attempt to find another basis for sex inheritance; but at present this hypothesis of the significance of the sex chromosomes seems the only intelligible one and the one therefore upon which further investigations must rest.

The question then arises as to how the sex chromosomes of *Sphaerocarpus* can be conceived as exercising their controlling influence. Apparently this question may be answered in different ways as regards the two categories of sex characters already mentioned.

The notion suggests itself at once that the differences in size and



in rate of growth of the respective gametophytes may well result from the difference in bulk of chromosome substance present in the cells of female and male respectively. The size of the X-chromosome is such that the chromosome group of the female exceeds in bulk that of the male, at a rough estimate, by perhaps fifty per cent. In view of this difference, and of the differences in cell size which in many cases have been shown to result from differences in chromosome number—as, for example, between haploid and diploid moss gametophytes (É. and É. Marchal, 1909), between haploid

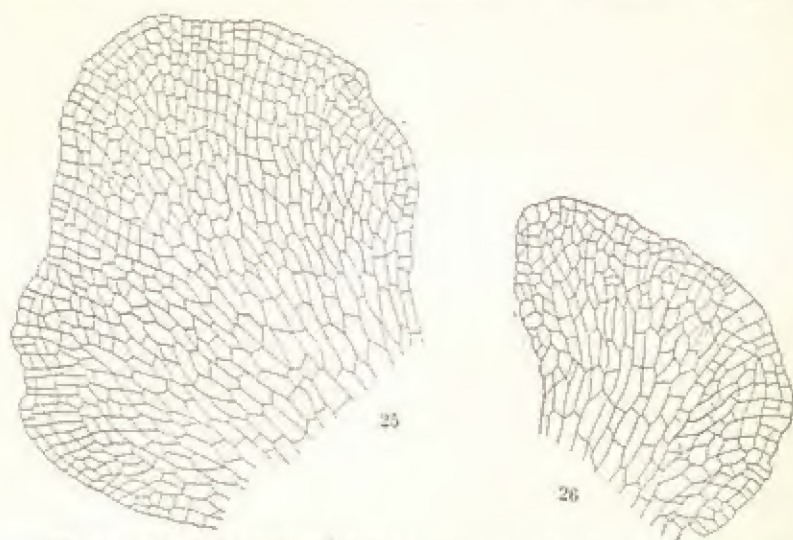


FIG. 25. A typical fully developed lateral lobe of a female gametophyte. FIG. 26. A similar lobe of a male gametophyte, drawn to the same scale. Both from greenhouse cultures of *Sphaerocarpos Donnellii*.  $\times 36$ .

and diploid *Spirogyra* cells (Gerassimow, 1901), and between the ordinary and *gigas* forms of tomato and nightshade (Winkler, 1916), it would not have been surprising to find a marked difference in cell size between homologous members of the male and female gametophytes of *Sphaerocarpos*. However, some measurements made to test this possibility showed that in corresponding parts, such as the lateral lobes, the range of cell sizes is substantially the same in the two sexes. This fact appears clearly in the camera lucida drawings of typical mature lobes from a female and a male

plant respectively (Figs. 25, 26), and of mature archegonial and antheridial involucre (Figs. 27, 28). These figures, while not negating the possibility of a small difference between the sexes in average cell size—a possibility to be tested only by a great number of measurements—demonstrate that such differences, if they exist, are negligible as compared with the difference either in total chromosome volume or in the total surface area of the chromosomes; and, what is more significant from the present point of view, that

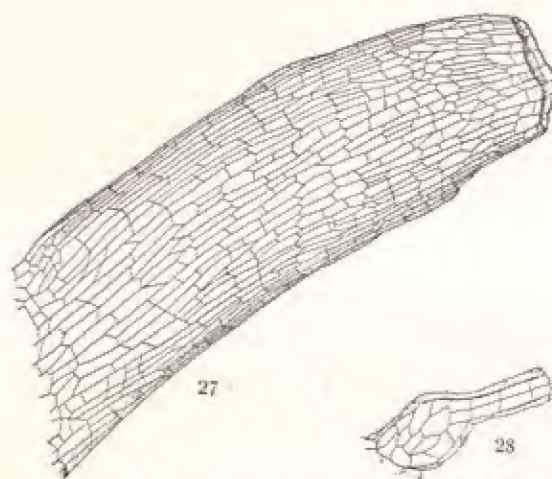


FIG. 27. A typical fully developed archegonial involucre. FIG. 28. A typical fully developed antheridial involucre, drawn to the same scale. Both from greenhouse cultures of *Sphærocarpos Donnellii*.  $\times 36$ .

such possible differences in cell size play no important part in bringing about the marked differences in size of homologous organs. On the other hand, as the figures referred to demonstrate, the characteristic differences in size between male and female plants result from the presence of a much greater number of cells in corresponding parts of the female. Since these size differences appear between plants of the same age, it follows that cell growth and division go on more rapidly in the female than in the male. If, therefore, the size and related differences between plants of opposite sex are determined by the difference in chromosome bulk, this quantitative difference produces its ultimate visible effects by means of its



influence on the rate of cell growth and of cell division. That this is the case seems conceivable and indeed probable, because the overwhelming evidence of an influence of the chromosomes on inheritance points to the exertion of this influence largely, at least, through a determination of the rate and nature of constructive metabolism; and one effect of a modification of the rate of metabolism would of course be an increase or decrease in the rate of cell growth and thus also in the rate of division.

But if such a simple quantitative explanation can be adduced to account for the influence of the sex chromosomes on the one class of sex characters, it cannot with equal ease be made to account for the characters of the second category—those which concern the form and structure of gametes, of sex organs, and of involucre.

It is true that, in connection with the observed facts in animals, several writers have suggested the possibility of a "quantitative theory" of sex determination, which would make all primary sex characters the expression of the amount or degree of activity of the chromosome material present. Without entering into the discussion of the validity of such a theory in the case of the metazoa, it seems quite impossible of application to the class of characters under consideration in *Sphærocarpos*. For one thing, it is to be remembered that in this plant, differently from the condition so common in the higher animals as well as in the dioecious seed plants, there are not two sets of reproductive structures, one functional, the other rudimentary but conceivably capable (certainly capable in many seed plants) of a normal development under particular conditions. In such a case the stimulus leading to the functional development of one set of structures or the other might conceivably result from the presence of a greater or less quantity of particular nuclear substances. On the contrary, the male plant of *Sphærocarpos* shows no trace of archegonia or of archegonial involucre; the female plant shows no trace of antheridia or of antheridial involucre. Nor can the differences between male and female structures be explained by modifications of cell size operating differently in different cell axes. Factors of some sort must be supposed to be at work which determine, very differently in the two sexes, the planes of successive cell divisions; which modify, also in very different ways, the nucleo-

cytoplasmic ratio; and which determine in the one case the considerable but relatively slightly specialized development of the egg, and in the other the remarkable metamorphosis of the androcyte into the antherozoid. This is but a partial analysis of the nature of the processes whose causes are to be explained, but it is sufficient to illustrate the nature and complexity of the problem.

Perhaps it is not safe to say more at present than that the appearance of the sex characters falling within the form-structure category are to be ascribed to factors which in some way are dependent upon, carried by, or inherent in, the X- and Y-chromosomes—the word “factor” here being used in its ordinary, not in a technical Mendelian sense. Nothing in our present knowledge of the mechanism of inheritance in *Sphaerocarpos* would justify us in holding that the factors here in question are of the nature of those which are postulated by any particular theory of heredity. The conclusion, if it can be so called, to which we are for the present led, is therefore that one category of sex characters is reasonably explainable by the difference in mass between the sex chromosomes; and that those of a second category seem to result from some other, but unknown, specific peculiarities of the same chromosomes.

On the analogy of the irregularities which, it seems well established, occur, though rarely, in the distribution of the sex chromosomes during the reduction divisions in certain animals, it is perhaps to be expected that irregularities more or less like these will be found in *Sphaerocarpos*. The occurrence of “non-disjunction,” for example, might lead to the formation of a tetrad two of whose spores have both an X- and a Y-chromosome each, the other two spores possessing neither. It would be idle to speculate as to the effect of such a distribution upon the viability of the spores or upon the sexuality or sterility of the resulting plants; but it is plain that the result might well be a disturbance of the normal 2:2 sex ratio.

Other irregularities than non-disjunction might conceivably likewise lead to modifications of this ratio; and so it will not be surprising should a study of the results of the germination of large numbers of spores bring to light occasional exceptions to the general rule of the distribution of sex characters. It is possible that some of the



apparent exceptions found by Douin were the result of an aberrant behavior of the sex chromosomes; but reasons have already been given for doubting whether these exceptions were other than apparent. In the examination of spore tetrads I have come across a few instances of spores joined in twos rather than in fours; and other instances in which a group consisted of two spores of normal size and one or two very small. Such conditions may result from an irregular distribution of the chromosomes; but they may equally well or perhaps better be explainable by the death or accidental injury or destruction of one or two spores after the completion of the division of the mother cell.

The existence of definite sex chromosomes having been established for two species of *Sphaerocarpos*, it is to be expected that similar bodies will be found in other plants. The most promising organisms for such investigations are probably the other dioecious bryophytes, especially those with a marked sexual dimorphism. Next would come perhaps some of the dioecious algæ. That previous searches for sex chromosomes in plants have been fruitless has been largely because they dealt chiefly with dioecious seed plants. Enough of these have now been examined to make it quite plain that no visible chromosome difference is to be expected as between the staminate and the pistillate individuals of any species. This negative result is quite in harmony with what we now know regarding *Sphaerocarpos*, because the distinction between staminate and pistillate sporophytes is of a quite different sort from that between male and female gametophytes; and if anywhere in the seed plants a chromosome difference is to be looked for exactly comparable with that described in the present paper, it must be between the micro- and the megagametophytes. Evidence as to the possible existence of such a difference is still meager; but such evidence as does exist is, it must be admitted, of a negative character.

In a previous paper (Allen, 1917a) I have referred to Hirasé's (1898) description of a cytological difference between the two antherozoids produced by the same microgametophyte of Ginkgo, which might be imagined to be the basis of the dioecism of the sporophytes of this species. This difference consists in the presence of a

conspicuous cytoplasmic body in one antherozoid and its absence in the other. The difference is brought about, not during chromosome reduction, but in the final division in the microgametophyte, and has no apparent parallel, so far as I know, in the cytology of any other diœcious seed plant. However, little or nothing is known regarding the corresponding division in other diœcious plants.

Correns' (1907) well-known experimental studies of sex inheritance in *Bryonia* seemed to show the existence in *B. dioica* of male gametes of two kinds with reference to sex potentialities. Correns, as well as most of those who have attempted an explanation of his results, has assumed that this involves the existence of two kinds of pollen grains, so strong has seemed the probability that the segregation of any particular hereditary factors is brought about by the reduction divisions. It is, however, quite possible to assume that, so far as sex potentialities are concerned, the pollen grains of *Bryonia* are alike, and that the segregation of sex potentialities occurs in the division of the generative cell within the pollen grain or pollen tube. This suggestion, though based only upon the obscure phenomenon recorded for Ginkgo, is perhaps worth testing, in view of the failure of all attempts to find other visible bases for the separate inheritance of staminate and pistillate characters.

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## THE APPLICATION OF SANITARY SCIENCE TO THE GREAT WAR IN THE ZONE OF THE ARMY.<sup>1</sup>

By BAILEY K. ASHFORD.

(Read April 24, 1919.)

It may be somewhat of a disappointment that I should present so little that is new to this Society, but war has requisitioned of science its application and not its theories and each man has been called upon to produce a result. The interest in this subject lies in seeing how far sanitary science could be applied on the battlefield and what part it took in winning this war. Let us answer the last question first:

In the Civil War there were 65 deaths from disease annually per 1,000 of strength; in the Spanish-American War there were 30; in the Greatest of Wars just concluded there were 14.8 and of these about 12 were due to epidemic pneumonia. That is to say, the medical sciences have kept 100,000 American men in fighting trim who would have in 1861 died of disease, and America needed those men. There was no time to get trained men from home, nor vessels in which to send them; the expense per man, the least consideration, was enormous, and, above all, if the liberty of the world was to be won at all it had to be done by the brawn of these very men and like men of our Allies. It had to be done *then*. The hour had struck. All the treasure and patriotic devotion of our country was helpless to do more in this crisis. When one reflects that never have armies been forced to live under more menacing conditions to health than those under which our soldiers lived and fought—at times, for military reasons, with reduced rations and much of the time underground, one cannot but wonder how it is that our generous people do not yield more than a passing thought to the scientist and to the science that made his invisible weapons. And the prevention of dis-

<sup>1</sup> Authority to publish has been granted by the Board of Publications, Office of the Surgeon General.



ease was only one of the activities of our medical sciences against the German. The part played by surgery, by medicine itself and by the skilful evacuation of wounded has yet to be written. We are apt to confuse our priestly mission of ministering to the suffering of friend and foe alike, with that militant one of applying our mind and body, our art and science, to win the war. A man who carries arms is not less a soldier for observing the laws of humanity in his treatment of a fallen enemy. A doctor who keeps healthy men at the front and salvages the sick and wounded to fight again is no less a soldier because he carries no rifle.

We went into this war with one officer per 27,000 men, one man in the division, charged *exclusively* with the responsibilities of the sanitation of our great fighting unit. He was only an advisory officer by law. He was a high ranking officer because rank is the current coin in the Army, and rank has its privileges. But he had strong support because he represented a reasonable and powerful science. Most commanders, jealous of the health of their troops, gave him every possible chance to work out his salvation. Some even gave him authority to command in their name. But the weak point lay in his lack of a force of trained men of his own to carry out his own suggestions. It was too much to require of fighting troops that they should lay aside their arms, often after exhaustive physical strain in the line, to build privies, delousers, etc. It was their duty to do their part but not all the creative work.

Again, this officer was expected to transform a new area into which the division would be suddenly thrust, into a sanitarily safe living-place for these soldiers and to do it right away. It was only when he failed to do it that he realized the full prominence of his position, for he was charged with the responsibility to his military chief for failure. This sudden assumption of responsibility for the sanitation of an unprepared area, or an area soiled by preceding troops, was another weak point. It is true that all medical officers of whatever condition are charged by law with sustaining the sanitary excellence of the command to which they are assigned, but "in addition to their other duties," and these other duties become in active periods paramount. In practice every one tried to keep things

sanitary, but only one, the division sanitary inspector, had nothing else to do and all he could *do* was request and advise.

But the Great War promptly threw the spotlight on these weak points and to its everlasting credit the Army began to evolve a plan to remedy them most skilfully. First, labor battalions began to be employed to prepare areas for troop cantonment, as well as to "clean up" after a battle. Two sanitary squads of one officer and 26 men were assigned exclusively to certain divisions for sanitary duty. These men were plumbers, pipe-fitters, carpenters, masons, tinsmiths and artisans of all sorts needed for carrying into effect sanitary plans. Engineer troops, quartermaster troops and even, when necessary, soldiers of the line, were to be called upon to help in work clearly beyond the scope and endurance of these two squads. But of all the promising steps taken in these reforms the plan of providing a permanent sanitary organization for Army areas was the best. Instead of a confused and hurried attempt every time a division was moved, to sanitize its new area by its own efforts at enormous expense, such efforts to be repeated more or less by the next division when in a week or so the first moved on, the Army, through its chief sanitary inspector, was to divide up its area into three sections, each of which was to be divided into from 8 to 12 subsections. These sections were plotted out for topographical reasons, and with an eye to highways, and had no reference to the divisions which might occupy them. The personnel was permanent and did not leave when divisions occupying their section left. They were Army units, under the military zone commander. They prepared the sanitary appliances for the incoming troops and helped keep them in repair as well as keeping a watchful eye over them. They exercised no authority over the troops using them,—they were there to help the troops keep decent and comfortable, as well as to prevent disease. The reason why they were Army units is that an Army is the least mobile unit in regard to its area. The divisions and corps were constantly changing. Each section had its chief in a town where he was to run a small school of sanitation and was to have a sanitary squad to build sanitary appliances for demonstration as well as to aid in repairing them in the sections which were being actually used. The sanitary squad at Langres was early stationed at the dump and from



its culls recovered enough lumber, metal, etc., to build 101 flyproof latrines, 67 urinals, 23 grease traps and 16 incinerators *in a month*. This was due to their commanding officer, Captain Starr A. Moulton, and shows how 1 officer and 24 men can provide a whole area occupied by the equivalent of a division with sanitary appliances and sanitize an area out of nothing, remaining on good terms with everybody.

The sanitary section of an Army area should be traversible in all directions by automobile and is thus constantly under the eye of the young sanitary officer.

The subsection is manned by a non-commissioned officer and two or three men, responsible to the section chief. They are his eyes—they give no orders, but are distinguished by an armlet and know everything that goes on in every nook and cranny of their territory, traversible on foot or horseback. They make themselves popular with shifting battalions who are only too glad of a helping hand and they keep the sanitary section chief thoroughly in touch with his problems.

The man who will make area sanitation a success must be a man who lives permanently in that area and who has this and nothing else to think of; who has planned and built its appliances; who will fight for them; who will enthuse the men personally in their proper use; stimulate competition; prevent waste; prevent heady unit commanders from blocking proper sanitary functions in his section; who will make himself a helpful and not a carping critic; who has a remedy and can do things as well as talk; who is not unreasonable but just a normal, sane, well-bred, well-educated gentleman with a keen sense of humor and an indomitable will; with his mental processes backed by scientific facts, his actions by common sense. In short, a man with enough of the prose of material results and the poetry of an invincible spirit to make a plan succeed, even if that plan is not a perfect one.

That is the sort of a man we want.

This leaves the division sanitary inspector with his two squads free to run the machine and not to make and run it at one and the same time. He administers the area and if he is at the front he has some time to devote to his legitimate duty, that of providing trench

sanitation, or the sanitation of an open battlefield, as the case might be. He has a divisional water-supply officer on his staff. He keeps a close watch on diseases which might become epidemic in his command and in epidemics works in coöperation with the chief sanitary officer of the Army. He is in close touch with Army laboratories and calls on them for special work.

#### EPIDEMIOLOGY.

The classification of communicable diseases and the administration of the epidemiologic service is based on an exposition of this subject made before the Army Sanitary School in Langres by Colonel Hans Zinnser, chief sanitary officer of the Second Army. This officer was working out these plans when the war came to a close and to him we are indebted for a prominent part in a great reform.

The Army chief sanitary officer should be an epidemiologist and laboratory man, as well as an administrator. He should keep spot maps showing the prevalence and source of infectious disease. In this he is largely dependent upon his section chiefs and divisional sanitary officers. He should have a stationary laboratory capable of becoming mobile at headquarters of the field Army, with two traveling motorized laboratories to dispatch to special work. I am not in accord with Colonel Zinnser in depriving a division of its mobile laboratory, but these two motor laboratories can be kept busy reinforcing division laboratories and checking their work. Infectious diseases are roughly divided into, (1) those disseminated by the respiratory tract: Pneumonia, influenza, measles, scarlet fever, meningitis, mumps, smallpox and chickenpox. (2) Those disseminated by the intestinal tract: Typhoid and its congeners, the dysenteries, simple diarrhea, etc. (3) Insect-borne diseases: trench fever, typhus, malaria, scabies, etc.

Communicable diseases depend for their extension either on the susceptibility of the individual or upon means and methods of transmission. For the first, such as meningitis and pneumonia, general hygienic measures were enforced with a degree of insistence and elaborateness of detail dependent upon the circumstances and serious-



ness of the local problem. The general measures employed to limit the spread of diseases disseminated by the respiratory system are:

1. *Hygiene of Living Quarters*: (a) A minimum of 40 square feet per man. If less, the suspension of shelter halves between bunks. (b) Head and foot sleeping in bunks side by side. (c) The spread of a command in tents in warm weather. (d) Ventilation by perflation once a day and once at night between taps and reveille. (e) Airing of blankets and bedding several hours on propitious days. (f) The invariable punishment of promiscuous spitting. (g) The sweeping of floors once a day after sprinkling.

2. *Hygiene of Mess Kits*: (a) Immersion after use in boiling water. Men were lined up after meals and made to dip their eating utensils in a ten-gallon, or larger, container of boiling soapsuds kept at ebullition by a hot fire. (b) Rinsing of same in flowing water. (c) Air-drying of same. No common towels permitted.

3. *Inspections of Command*: (a) Men lined up and inspected twice a day for head colds, cough and inflamed eyes. (b) Temperature taking of men not feeling well. (c) Segregations of all coughs, colds and red eyes in a separate barracks or curtained-off portion of a common barrack. (d) Evacuation of all with fever to a hospital.

4. *Inspection of Men's Personal Equipment*: The verification of possession by each man of a raincoat, an overcoat, two pairs of shoes, three blankets and three pairs of socks.

5. *Provision for a Drying Room for Clothing*—a vital necessity in France.

6. *Avoidance of Excessive Labor*. Drills and fatigue duty should be cut to a minimum to avoid exhaustion, fatigue being a well-known condition of inviting infection by lowering individual resistance.

The majority of these measures could only be enforced in rest areas. In combat, naturally, no sensible man could consider the employment of more than a tithe of these protective measures.

The general measures employed to prevent dissemination of diseases by the intestinal tract are:

1. *Care of Latrines*:

(a) Fly-proofing (area sanitation).

(b) Disinfection of interior of receptacles and latrine seats during an epidemic (divisional sanitary squads).

- (c) Ablution benches or other provision for handwashing after use of latrines (area sanitation).
  - (d) Prohibition of towels.
2. *Sanitation of Kitchens:*
- (a) Neatness and cleanliness of kitchen itself and utensils.
  - (b) Prohibition against use of uncooked food.
  - (c) Enforced hand cleanliness of kitchen crew.
  - (d) Medical inspection of kitchen personnel and all handlers of food and removal of all sick or sickening, as well as carriers.
3. *Surveillance of Drinking Water:*
- (a) Proper chlorinization of water and a bacteriological examination of disinfected water from time to time as a check thereon. (Division sanitary squads and Army mobile laboratory.)
  - (b) Careful supervision of water sources and guard therefor (unit commander, division sanitary inspector, sanitary section chief, engineer water supply details, Army mobile laboratory).
  - (c) Supervision over water carts (division sanitary personnel).
4. *Disposal of Garbage and Offal:*
- (a) Soakage pits for liquid waste.
  - (b) Incineration, or sale, or other, disposal to civilians of solid garbage.
  - (c) Prompt burial of carcasses.
  - (d) Removal and proper disposition of manure (burning was impossible).
5. *Prompt Notification of Military Chief when in the Presence of Epidemic Conditions.*

It will not be amiss to consider briefly the *Special Procedures* for *Special Diseases*.

*Typhus* and *trench fever* require careful destruction of lice, the carriers of these diseases.

*Typhoid* and *congeners* were practically eliminated from all Armies by vaccination. The few persons who acquired typhoid fever were especially susceptible and did not receive a large enough preventive dose of the vaccine; were recipients of an overwhelming



dose of virulent organisms, or, through carelessness, were not properly inoculated.

*Influenza* demanded prompt evacuation in separate ambulances, segregation, and masking.

*Smallpox* called for strict quarantine and vaccination.

*Trench foot*: Issuance of dry socks at dinnertime, when in the line, or in very muddy terrain elsewhere; powdering of feet with a combination of camphor, salicylic acid and talcum; mutual massage of feet, after removing shoes, in groups of two when in the line; precluding of foot and leg covering which constricts the circulation; drying of shoes at every favorable opportunity.

*Venereal disease*: Propaganda, prophylactic stations and surveillance of civilians. Applicable in cantonments.

*Tetanus*: Universal prevention dose of antitoxin in all wounds and in trench foot.

*Boils and other infective inflammations of the deeper layers of the skin*: Inspection of men at baths for scabies and other sources of irritation of the skin, and segregation under treatment. These skin affections, plus lousiness which often caused trench fever, were responsible, it is said, for a full 90 per cent. of all incapacitation from disease in a British Army.

It is extremely interesting to review the experience of the French and British during the long months of war preceding our entrance into these scenes, a time when experience, that bitter teacher, was elaborating for us the saving knowledge that Briton and Gaul turned over to us for our protection, without a thought inspired by selfish pride, or the slightest attempt to cloak their own shortcomings, that by these truths our men should live to fight.

When the war broke upon Europe, France, we were told, had no compulsory vaccination against typhoid. The result was that for the first six months, due, in part, to a life-and-death struggle in which only military resistance could be considered, typhoid ran rampant. No one knows how many cases developed in the French Army; one French officer named a figure that is so high as to be almost incredible. Compulsory vaccination wiped out the disease from this Army in the succeeding months. In the British Army 90 per cent. of her men were inoculated against this disease with the

result that there were only 7,700 cases of a strength of 2,000,000, throughout a period of 40 months of campaigns. Compare this with their record in the South African War when, of a force of 100,000 men, and very few vaccinations, there were 56,000 cases and 8,000 deaths, and with the record of the first American Army of one million men, which according to its Chief Surgeon, Colonel Alex. Stark, had only 17 cases of typhoid and 10 of para-typhoid to January 1, 1919. With tetanus in 1914 there were 32 cases per 1,000 wounded; in 1917, a small fraction of 1 per cent., the favorable change being due to strict orders that all wounded should be given a preventive dose of the antitoxin.

In the first British Army in 1915-16, 3,311 cases of trench foot were evacuated; in 1916-17, only 395. In the fourth French Army in 1916-17, 2,861 were treated for trench foot. As a result of the clear enunciation, in time, of the preventive measures to be taken, practically no cases developed in the American Army.

Availing ourselves of their knowledge, plus the proof by Strong, of our Army, on suggestive evidence presented by the British that trench fever was carried by lice, plus the experience of both French and British that the destruction of insect life in clothing would enormously reduce morbidity, the American Army, with its own enlightened medical corps, reinforced by the frank testimony of the Allied troops, was able to produce a record for preventive medicine in war the like of which the world has never before seen.

All of these precautions above noted being in force and all of the special sanitary appliances for this war in function, there remains a general statement to be made: The chief cause of sick wastage, when sanitary science has already yielded its utmost, is reduced vitality from overwork, little sleep, poor food and constant cold. Many of these undesirable conditions are inseparable from certain military necessities, but it is an ill-conceived idea of a commanding officer that troops to be efficient should do arduous service and at the same time be deprived of possible comforts and prime necessities "in order to harden them," such as sleep. In such a war as the one through which we have just passed, this is not the time nor the place to weed out the men with slight imperfections capable of gradual remedy. The wise commanding officer will endeavor, where



the whole male fighting population of his nation is requisitioned for war, to keep all of his men and not only those who can rise above his own peculiar selective processes. It is vicious to get men up before sunrise, give them their breakfast in the dark and start them out in the cold morning mist, chilled, unfed and with clothing still damp from the rain of the day before to do a hard day's work, again terminating in wet and cold. It is still worse to gather such men after supper with clothes still wet for lectures running far into the night. This "intensive training" may break down a man before he has the opportunity to deliver a blow, not only the palpably weak, but, to our surprise, the apparently strong. Our Field Regulations preach against this, our best officers of the old Army condemn it, and it is only mentioned to deter a well-meaning but inexperienced newcomer from a dangerous point of view. The best officer knows how to care for and feed his men and the best troops are faithful witnesses of the effect of the care bestowed upon them.

#### THE SANITATION OF TRENCH WARFARE.

##### *In the Trenches.*

Sanitation is reduced to its simplest terms in the trenches. It has to be. Men are there to fight. In the brief week or ten days they are there before their relief, lights, smoke, evacuation, building, are taboo. Moreover every nerve is taut to get the best of the enemy and there is little time for things of immeasurably less importance, however simple and enticing the procedure may seem. Sanitary science is reduced to its barest necessities and then greatly reduced from that point.

*Latrines:* These are either buckets under a flyproof seat or flyproof boxes over a pit in a blind offshoot from a communicating trench. There is a camouflaged head cover and there should be a can or trough leading to a soakage pit for urine. Pit latrines should be deep and buckets emptied in adjacent shell holes at night, as is garbage from food brought up to the men.

*Water:* This, in well consolidated positions, is pumped from a chlorinating source. It may be stored in cement water tanks or carried up from water carts in the rear. A trick of our soldiers was

to fill a large number of canteens in the rear, string them on a pole and thus carry them up. Water may be obtained from wells in dug-outs and, after filling the 40 gallon canvas Lyster bag, and disinfecting with hypochlorite powder, be doled out to the men. Best of all it may be piped up, but this could only be depended upon in very quiet sectors, as bombardment quickly broke down such a system.

*Food:* This is usually sent up once a day from kitchens in a communicating trench somewhere in the rear and is kept hot by storing food for 16 men in a marmite, or thermos can. There is a special danger in these cans, when the lid is left off until the temperature falls to blood heat and the lid then replaced, from fermentation, which may cause serious food poisoning.

*Clothing:* Dry socks should be supplied with the evening ration when men are standing in wet trenches. The necessity of standing in muddy water is the only excuse for the rubber boot, otherwise an abomination.

*Drainage of trenches:* Well-constructed trenches are floored with a duckboard path and under-drained by a gutter with occasional sumpholes which are emptied by suction pumps in favored positions.

*Drying rooms:* Every trench position of any permanence should provide these rooms, necessarily in a dug-out, and a brazier coke stove or two will be sufficient to accomplish satisfactory results.

*Heating* of dug-outs is by braziers. *Ventilation* by stove pipes with closing apparatus in case of a gas attack. *Light* by candles, kerosene lamps, acetylene or electricity, but oil lamps require oil to be brought up, a thing possible only in times of inactivity, acetylene is practically confined to medical dug-outs and electricity is only available in well-consolidated positions, long occupied.

*The Sanitary Duties of the Battalion Medical Officer:* The sacred relations established between this lone representative of our great profession and the soldier in his hour of trial is readily seen in the influence this officer wields for the prevention of disease. It is a personal relation. He talks to no audience and he indulges in no flights of fancy. A good battalion surgeon knows all the men; he is over in the trenches; he knows when the breaking strain has been reached in Jones and he laughs Smith out of his "shell-shock." He invents a thousand ways to make the men more comfortable,



supervises the simple sanitary arrangements of his sector and catches the first signs of a communicable disease in his command. The trench is no place to keep a sick man, but it takes a real doctor to determine whether he is sick, worn out or ailing. All communicable diseases are immediately evacuated if possible, but many an incipient "shell shock" or case of homesickness has been exorcised by a keen young medical officer in the trenches. One of his great duties is to "keep men on the line" and the man who aids in doing this has a friend in the battalion commander. There is no one for whom the men have greater respect, in whom they have greater faith, for whom they entertain a more loyal affection than "their doctor" unless it be their own personal commander, and this is as it should be. This picture has been attempted to show how strong a representation sanitary science has at the elbow of the fighting men and that it is this human touch, humanely administered, that makes the practice of hygiene possible among our troops. The most that we ask, that we require, of our men *under fire* is to be as clean as possible and decent always.

#### THE SANITATION OF OPEN WARFARE.

Here sanitation is reduced to a mere shred, but the little that can be done often makes the difference between ultimate victory or defeat.

The essentials are:

1. Hot food,
2. Disposal of feces and urine,
3. Safe water,
4. Burial of bodies and carcasses,
5. A reasonable amount of rest.

Food is supplied by wheeled kitchens, a great boon to soldiers. Hot liquids are a tremendous stimulus to exhausted soldiers and the measure of good done by our Red Cross, Salvation Army, Knights of Columbus, Y. M. C. A. and other patriotic societies to soldiers going up to and returning from the battlefield has left a grateful memory in the soldier.

Pioneer battalions are absolutely necessary in these modern wars. They should follow the troops, bury animals, bodies, etc., burn refuse

or bury it, dig latrines and are at times indispensable in many ways. Unburied bodies and carcasses rapidly breed myriads of flies, streams polluted by dead are contaminated with their intestinal bacteria, the thirsty and tired men drink the water on the line, sicken and their germs of disease raised by passage to high virulence, and teeming in uncovered feces, are carried back by these flies to spread like a wave of cloud gas over the food of advancing reinforcements.

Latrines are mere straddle trenches a foot wide and a foot deep. They must be scrupulously covered by some one.

The question of safe water is settled by chlorinization. If the Lyster bag cannot be used, an ingenious American device is the dosing of the contents of some sergeant's canteen with a full tube of the powder, a plan suggested by Zinnser. The men can be advised that all they have to do to get safe water from the battlefield is to fill their canteens from any possible, unpoisoned source and put "a little," about a teaspoonful, from the sergeant's canteen into their own. In about 20 minutes they can drink reasonably safe water. No one will ever know the thousands of American lives saved by the bag devised by Colonel Lyster, of our medical corps, in the Great War. Vaccination against typhoid is not everything.

#### THE BACK AREA IN TRENCH WARFARE (POSITION WARFARE).

This is itself a subject for another paper. Only essential sanitary arrangements necessary to complement trench life will be mentioned.

##### *Bathing and Delousing.*

This should be at least under the supervision of the medical department for it is a powerful weapon against disease, as has been seen.

All men returning from a tour of duty in the trenches are put through the bath and delouser. The underlying principle of importance is *not* the bath; it is the killing of vermin and itch mites on clothing by heat. There should be two per division with an output of one thousand a day. There should be a medical department floor-walker to detect all skin diseases.



*Types of Delousers.*

The Fodden-Thresh single-cylinder and double-cylinder steam sterilizer for disinfection under pressure.

The French Autoclave of like type.

The Jacobs hot-air chamber and Orr Canadian hot-air chamber.

*Types of Bathing and Delousing Establishments. French Army.*

This is known as the personal hygiene section and it is run by the French medical department. Upon its general principles our American baths were run.

Personnel: One non-commissioned officer, a sergeant, two corporals, three mechanics, one barber and 10 men.

Bathers were admitted in groups of 40. It is a test unit. It consists of one store tent, Bessonneau, for clean clothing, one tortoise tent for storing soiled clothing, one tortoise tent for barber and chiropodist, one tortoise tent for valuables, and the bathhouse. The men on first entering the bath place their valuable in an individual bag bearing their bathing number. This bag goes into a basket which is locked and placed in the tortoise tent until they return from the bath. They now receive their bath number on a wooden tag, go to Room A of the bath house and look for their bath number painted on latticed seats in the center of the room. Here they undress, throw their underclothes on the floor, and stuff their outer clothing and shirt into a mesh bag with a tag bearing their number. This goes into the sterilizer. They keep their hats, their gas masks and their shoes to carry into the bath room. In the bath room these are placed in a cubby hole numbered with their bathing number.

Upon entering the undressing room, an attendant notes the size of the man for replacement of underclothing. There are only three sizes; one for short, one for medium and one for tall men.

A reserve of 10,000 suits of clothing is kept in the store tent and includes the following: Shirts, drawers, undershirts, stockings, towels, and handkerchiefs.

Each disinfecter holds 40 kits, each composed as follows: Breeches, blouse, overcoat and pair puttees. The autoclave is a very handsome one and it has a steam ejector for creating a vacuum and drying coils for driving off steam after sterilization.

There is a hot-water tank on top of the autoclave which feeds the showers and gives a pressure up to one kilo by manometer. There are twenty shower heads. Water is heated to 38° C. and kept at that temperature by a cold-water mixer. A bell rings when 45° is reached.

The autoclave is drawn by two horses and the weight is 2,000 kilos (4,000 pounds). To set up this portable bather and delouser it is necessary to be near a watercourse giving at least one liter per second, and to have space up to at least 5,000 square meters. It takes two hours to set it up and eight hours to make ready for the first bath.

These baths require about 12 liters of water per man. Men are allowed, normally, ten minutes for actual bathing and it requires a minimum of twenty minutes to hand them their deloused outer clothing. Soap and towels are furnished by the bathing establishment and the dirty, but deloused, underclothing is stored in a tortoise tent to be trucked to the laundry after bathing hours if distant, an equal amount being returned clean from their store in exchange.

The English variation from this bathing establishment lay, as a rule, in the delouser itself. Toward the end of trench warfare disinsectization was accomplished by dry hot-air chambers. The most elaborate type of these is the Jacobs and the easiest to construct and run is the Canadian Orr which will be described. It can be built in a few days by four pioneers. It is essentially a hot-air chamber with double iron walls and the space between insulated by earth. It is heated by under-burning coke braziers and ventilated by holes into which fit wooden plugs, removable, to regulate the temperature. The loaded chamber attains 65° C. in ten minutes.

We were experimenting at Langres on a combination of bathing house, incinerator and laundry all in one, when the war came to a close.

#### *Portable Hot-Air Disinfestor.*

The Pleasants hot-air disinfestor and portable shower for companies or battalions. Mounted on Army general service wagon; has a limited application for service nearer the front.

The Serbian barrel will not be detailed as it is far from satisfactory and when used is a makeshift. The same principle on



wheels, devised by the French with a portable bath was however a most ingenious application.

Men should be bathed at least once every ten days and deloused at least once a month. Hence battalion organizations were each furnished, in our Army, with a Charles Le Blanc heater and 8 head showers, in addition to divisional baths.

Every rest area should have its cobbler shops, its tailor shops, and its barbers. They are, as are baths and delousers, run by Class B men, generally. Dirty, ragged men lose respect for themselves. "Smartness" has a determining influence on the soldier *at the front*.

*Billets.*—Neatness and cleanliness are the keys to their successful employment. Our men did wonders in tidying up stables, barns and outhouses in France. Scabies in a billet required "delousing" of all blankets and a working quarantine, if feasible, of occupants. The English greatly feared scabies and an English chief surgeon insisted that much of it was spread on latrine seats.

#### *Kitchens.*

Time does not permit their discussion, which offers much of interest. The main desiderata are:

1. Cleanliness and simplicity of equipment. A clean kitchen inspires a good appetite. Everything that shows should be immaculate and always in its place. Men should be allowed to help themselves from a common receptacle and be told to never take more than they want, but always come back for more if they were still hungry. The English said that they saved 10,000 pounds in that way in a year at one large camp.

2. All grease should be salvaged and sullage water deprived of its grease by traps. The water then percolated into the earth without clogging its pores after being led into a filtering cess-pool or "soakage pit."

3. All scraps of food, especially bread and meat, were saved and made into tasty dishes at subsequent meals. This means not only the teaching of cooking to cooks, but of "catering" to mess sergeants. A full garbage pail became a poor recommendation for any unit in the A. E. F.

4. A brick or cement floor was most desirable in a kitchen and whitewash and tar liberally applied at least helped as an appetizer.

5. Cooks should be *compelled* to wear white caps and aprons in the rest area. Dirty cooks mean dirty food—and generally a “full garbage pail.”

6. Menus should be varied and stews should not figure on more than 3 days in the week. Meat should be stored in meat safes and “quarters” should be hung, haunch down, and covered with burlap or muslin bags.

We labored with the generally acknowledged defect that the culinary art in the United States had declined. “Canned stuff” was offered as the solution, but with all its virtues it can never replace art. Besides it is at least debatable whether a preponderance of canned foods is more desirable than a fair representation of the dishes “that mother used to turn out.” But the great, the crying, sin was the capacity for enormous waste of food material “not equalled by any country on earth,” an Americanism we carried with us to Europe. Our Army manfully struggled with this generous failing and certainly improved the situation, but it was only by persistence that real saving was accomplished.

#### *Latrines.*

The ideal latrine for troops under ordinary conditions was the deep pit and flyproof box seat. Even the English acknowledged this, but it should be from 10 to 12 feet deep. The seats should be cleaned inside and outside daily and blackening of the pit with lamp black and crude oil is desirable. The trouble was we could not get crude oil. Burning out of pits was also impossible; there was no mineral oil “to waste.” Hence the American Army devised their own latrine, a cross between the American and a French commodity. It was simply a deep pit rimmed at the surface by two-by-fours with a platform covering it in. Every two boards were nailed down. The intermediate one was loose and could be removed by a handle or a pole fixed perpendicularly in the center. Thus there was no seat, the simple concession of the French to economy. It was flyproof when the loose boards were replaced. The British, on the other hand, provided what was for most cantonments, in France, the



most feasible and certainly the most sanitary arrangement; the bucket latrine and incinerator. Pits could not be dug in many places ten feet deep without striking water or rock. Besides, the French bitterly opposed, and with reason, the digging of pits for feces. The incinerators built by the British usually served 800 men and were models of practical common sense and good sanitation. They usually presented a hopper leading down onto a hot plate for drying of excreta before dumping the contents upon the fire and this served for solid garbage as well. Often a few coils of pipe were led around the fire box and heated water for an ablution bench nearby. Everything about the incinerator could be built with stones, old bricks, a little cement, old rails, old bits of iron sheeting, etc., and in an incredibly short time. The fuel was ostensibly at the rate of 100 pounds a day. In reality 2 pounds of coke was used to start the fire and the thing was kept at full blast eternally, like the altar fires of the Vestal Virgins, by camp trash. This kept the camp clean because the incinerator was served, as were these altar fires, day and night, by a husky soldier looking for a fuel economy record; the camp was carefully gleaned daily and gleanings deposited by that incinerator. The latrine was nearby, a long shack with usually a cement floor, flyproof seats and, under each seat, a bucket. In front of the seats was a urinal, a metal water way leading down into a soakage pit. A little cresol stood in each bucket and before incinerating the contents a good 20 per cent. of saw dust was added to insure incineration. The buckets were emptied twice a day and smeared with crude oil, which they secured in some manner, before replacing. I never detected the odor of feces in any British camp I visited. Critical eyes may challenge this statement, but no one will testify that the bucket latrine was a failure if they saw enough of them. The English became so bold that they would place their bucket latrines near their kitchens and mess halls. This, with the proximity to ablution benches, where hot water was obtainable for the morning shave, very much simplified daily routine and stimulated cleanliness and an orderly observation of sanitary principles. The answer of the British to an objecting theorist would invariably be:

"If you have clean latrines and burn your feces you need not fear flies."

In concluding this long paper we are compelled to the reflection that, after all, the great point is that it was not only mechanical sanitary appliances that we were after but the sensitizing of our soldier's conscience by appealing to his sense of decency. The immediate commander of troops must inculcate in his men, in addition to a strict regard for military discipline, a decent regard for the ornate, and as a result thereof, for the clean and neat. It should be deliberately taught men that it is not enough to have merely the "rough stuff," the bare necessities; that civilized men are expected to improve their natural condition; that they should keep themselves and their surroundings clean if they expect to keep well; that they should keep their initiative, their ambition, their imagination active; that to make their barracks, their reading rooms, their camps clean and attractive to the eye is to preserve those illusions of life which are necessary to make men contented and happy.

Nothing illustrates this spirit better than the following incident: When the First Division was in a training area under the tutelage of the famous and gallant 47th Division of Chasseurs, the disposal of manure piles in the center of these tiny hamlets was a sore trial to us American officers. The French had some towns for billeting and we had others. One day in traveling over the French area with Colonel Cultin, their division surgeon, I noticed that none of his towns possessed the protruding manure pile beside the neat little house in the main street. On inquiring how it was that no amount of coaxing or threatening by French civil authorities had prevented their reappearance in our towns, he replied: "We removed the piles to the site the owner selected himself out of town, and planted flowers where they used to be—and no good French peasant will smother growing flowers with manure piles."

Nor will an American soldier spit on a clean floor, nor befoul a neat home, which he has been led to beautify by his own efforts.

It may seem trite to mention that neither laws in a civil community nor regulations in the Army are alone potent to sanitize one or the other. There is a difference between securing the precision of a machine in a military organization and considering a



man simply as a machine. Germany had the most perfect machine in the world and she failed. She persistently bid us to treat our men as machines and she herself failed. It is the spirit of a glorious France that bespeaks our own American heart and the words are from the favorite work of a brave and humane officer, idolized by his men, Major General Goubeau, given me personally as his division watched the road to Metz:

"Le soldat n'est point une machine. Avant d'être une unité de groupe, il est une personne."

SURGEON-GENERAL'S OFFICE,

WAR DEPARTMENT, WASHINGTON, D. C.

April, 1919.

## STAR CLUSTERS AND THEIR CONTRIBUTION TO KNOWLEDGE OF THE UNIVERSE.

By HARLOW SHAPLEY.

(Read April 25, 1919.)

Social relationships among stars are nearly as common as among men and the lower animals. Sidereal bodies completely independent of all star societies are difficult of conception; for the heritage of early and ancestral associations, as well as the immediate environment, influences the present behavior and the destiny of stars. Planetary systems, binaries, groups of three or four nearly equal bodies are thought to be very common—almost universal, it may be; and the assemblage of stars of all kinds by the tens, hundreds, and thousands into physically organized clusters now appears to be a property of fundamental significance in stellar investigations.

In considering the aspect of clustering among the fixed stars we see a gradual progression from the largest and most scattered constellations to such rich and highly concentrated stellar groups as the globular clusters. Although the constellations were outlined for the most part in prehistoric times and have been used in myths and astrology persistently and universally throughout thousands of years, in general they do not represent definite physical organizations that exclude the stars of neighboring groups; and frequently even the legendary relationships of the stars in the most anciently known constellations are traced with difficulty.

There is, however, among the varied groupings, an easy transition from widely-scattered Ophiuchus and Camelopardalis to Orion, Scorpio, and the Great Bear; and in recent years we have found that the most conspicuous stars of these three last named constellations actually form physical stellar systems. The stars of each have motion, colors, and distances much in common, and in each case they have evolved, no doubt, from an origin common in space and in time. From Orion we readily trace the progression in clustering



to the Hyades—a more compact and more definitely circumscribed dynamical system—and then to the Pleiades, to Præsepe, to the double cluster in Perseus and similar faint loose clusters of the Milky Way; thence, by way of Messier 11 and Messier 22, we proceed by nearly equal steps to the typical globular systems exemplified in the great Hercules cluster, Messier 13.

Although we may justly restrict the term “star cluster” to physical systems—that is, to groups which have the characteristics of distinct dynamical organization—it is clear that the subdivisions of the long sequence of groups from Orion to the Hercules cluster must necessarily be vaguely defined. For convenience we here distinguish only open and globular clusters, and designate all as open except those seventy or eighty highly condensed groups whose stars appear innumerable even with the aid of our biggest telescopes and most sensitive photographic plates.

Open and globular clusters differ in matters other than richness and apparent circularity. In average distance from the earth the globular clusters much excel, in stellar constituency they are more varied, and we recognize in their wide spatial distribution that from a dynamical point of view the globular clusters are quite distinct from the open groups which closely congregate along the middle line of the Milky Way.

A few of the nearest globular clusters are visible to the unaided eye as faint hazy objects, and some of them have been in the astronomical records for two or three hundred years. To Messier and earlier observers they were known only as starless nebulosities, but Sir William Herschel and his son, with their greater telescopes, partially or completely resolved the brighter clusters into myriads of distinct stars.

The great telescopes of the present time and the powerful modern methods of astrophysical investigation have greatly extended our knowledge of globular clusters, but they have not appreciably added to the total number. The numbers of known stars and nebulae have increased enormously with the increase of optical power, but during the last eighty years less than five new globular clusters have been added to the original lists compiled by the Herschels. In fact, we seem to have passed the era of discovery of such systems; the pres-

ent lists may be considered essentially complete—a condition that does not prevail for any other important type of celestial object.

It has been shown through the studies made at Mount Wilson that most of the globular clusters are remotely isolated systems, neither intermingled with nor closely surrounded by other stars. They may be treated, indeed, as distinct cosmic units; and in treating them as such, we may fulfil the purpose of the present communication by discussing briefly a single system. In certain details, there are, to be sure, conspicuous differences from system to system, but in such matters as size, number of stars, and stellar make-up, no greater diversity appears.

The Great Cluster in Hercules, No. 13 in Messier's well-known compilation of 103 bright nebulae and clusters, is the system chosen for the present illustration. To the unaided eye it is faintly visible as a hazy star of magnitude 5.8, about two degrees south of Eta Herculis. The photograph used for this illustration was made by Professor Ritchey on a plate of medium rapidity with an exposure of eleven hours; it records something like 30,000 stellar images brighter than the twenty-first magnitude. Nearly all of these are actual members of the cluster and not merely objects of the foreground, projected among the cluster stars.

The distribution, brightness, and colors of many hundreds of the stars in Messier 13 have been specially studied at Mount Wilson. Some attention has also been given to spectral types and radial velocities—difficult problems even for large telescopes and powerful spectrographs because of the extreme faintness of the individual stars. Space cannot be given here to describe the methods recently developed for the determination of the distance of Messier 13 and other globular clusters; we shall only remark that photometry, astrometry, and spectroscopy are all involved, and that Cepheid variable stars play a fundamental rôle. The adopted value of the parallax for the Hercules cluster is  $0''.00009$ , with an estimated uncertainty of less than twenty per cent.

Even to those who are accustomed to think of the great depths of sidereal space, it is difficult to comprehend clearly the remoteness of the Hercules cluster. Its distance,  $3.5 \times 10^{17}$  kilometers, is more than eight thousand times that of the nearest star now known.





FIG. 1. The Globular Cluster, Messier 13.

Light, traveling with its hardly conceivable velocity of 300,000 kilometers in a second of time, requires eight minutes for the passage from the sun to the earth, but it must travel more than two thousand million times as long to reach us from this globular cluster. Hence our knowledge of the position and physical characteristics of Messier 13 does not refer to the system as it now exists. Our

most recent information dates from the time the light we now receive left its remote origin in the cluster, and what has occurred there during the last 360 centuries is beyond our power of finding out. On the basis of our knowledge of the probable causes of these past conditions, we may believe with good reason that the cluster is now much as it was 36,000 years ago. Such an interval of time is of small consequence in the life history of a gigantic stellar system; but while these pulses of light have been coming across the intervening fraction of unending space a thousand human generations have come and gone; man has emerged from a vague, unrecorded past and in fleeting succession all his historically known national civilizations have slowly evolved, flourished in vaunted permanence and supremacy, and quickly relapsed into oblivion or poor mediocrity. We recall, too, that of all the globular clusters whose radiation is continually streaming toward the earth, Messier 13 is one of the very nearest.

With the distance of the cluster known, we readily translate angular dimensions, as measured on the surface of the sky, into linear dimensions. Thus, by the definition of parallax, the angular value  $0''.00009$  corresponds in the Hercules cluster to one astronomical unit—the distance separating sun and earth. By transferring a linear scale to the cluster, therefore, as in the accompanying illustration (which does not include the outlying stars), we may determine the separation of the individual stars, the number in a given volume, and numerous other facts concerning the physical structure of the system.

It is worthy of emphasis that in determining the distance of the Hercules cluster we have at the same time derived the distances of its tens of thousands of stars. The absolute values of these distances appear to be accurately known; and certainly the distances of these stars relative to each other are known with an accuracy that is unequalled in ordinary parallax work, for in any given globular cluster the distance of all the stars from the earth may be accepted as the same, with an error of less than one per cent. We are thus in a position to make some general investigations of the inter-relationships of the brightness, colors, numbers, and positions of stars; and, because of so little uncertainty in the relative distances



and because of the great numbers of stars available, we can make these investigations with more ease and accuracy in a globular cluster than with the bright stars around the sun.

A conception of the great size of a globular cluster may be gained by indicating on the picture of Messier 13 some of the familiar distances of the solar neighborhood. The distance separating the nearest known star (Alpha Centauri) from the sun is indicated by the short black line near the center. In the cluster, within the corresponding distance from the center, there appear to be thousands of stars, illustrating how greatly different from the conditions of our own immediate part of the universe is the concentration of mass and luminosity in a globular system. The distance to the Hyades, the well-known group of bright stars in Taurus, is represented on the photograph by the distance from the center of the cluster to the star marked *H*. The diameter of the large circle is about fifteen minutes of arc on the surface of the sky, corresponding at the distance of the cluster to ten million astronomical units; a sphere of that diameter with the sun at the center would include all the stars within eighty light-years.

The total angular diameter of the cluster is about thirty-five minutes of arc, corresponding to twenty-three million astronomical units, or more than three hundred and fifty light-years.

All the cluster stars shown on the photograph are giants in actual luminosity. At the cluster's distance of 36,000 light-years, a star as bright as our sun would be considerably fainter than the twentieth magnitude and would not appear on this reproduction. The three stars whose images are enclosed in small circles are photographically almost exactly one hundred times as bright as the sun, and the most luminous giants in the cluster exceed a thousand suns in light emission.

It is a remarkable fact that the brightest of these cluster stars are red and the fainter ones are blue. The red stars, because of low surface temperature, emit much less light for a given amount of surface area. To excel in brightness, therefore, their volumes must be enormously large—in extreme cases more than a hundred thousand times that of the sun, and, since stellar masses in general are probably not very unequal, the mean densities of these red giants are correspondingly small.

Although these cluster stars are gigantic when compared with the sun, and are highly concentrated into a compact and symmetrical organization, they do not differ in physical properties, so far as we now can tell, from hundreds of isolated stars of the Galaxy. Many of the naked eye stars equal them in light power, in color, in volume. The Cepheid variables in the cluster have light-curves, color variations, and spectra like those of the variables near the sun. In other words, the members of clusters are normal stars.

Until recently the globular clusters have been accepted as spherical in shape. When projected on the sky we should therefore expect them to be circular in outline, and, except for accidental errors of distribution, the number of stars should be the same whatever the direction from the center. A systematic study of the photographs at Mount Wilson has shown, however, that a majority of globular clusters, as seen in the sky, are slightly but symmetrically elongated. This condition has been interpreted as a flattening of the cluster system—an indication that the clusters are not spheres but rather are oblate spheroids or ellipsoids. Messier 13 is one of the most flattened; and though the elongation, in the direction indicated in the picture by inclined white lines, can be uncertainly seen, either visually or on photographs of the cluster, it is very readily shown by counts of the individual stars. There are about thirty per cent more stars in the direction of elongation than at right angles thereto.

The flattening suggests that this great stellar system may be in rotation about its shorter axis. Observations have not as yet determined whether or not such a motion exists. It is known, however, from spectroscopic work at the Lowell Observatory and at Mount Wilson, that the cluster as a whole is moving with the high velocity of two or three hundred kilometers a second. Noting that the mass of the whole cluster is probably in excess of 100,000 suns, we appreciate that the momentum of this moving cosmic unit must be exceedingly great.

The only component of the motion of Messier 13 now known is directed toward the earth and toward the greatly extended strata of stars that constitute the galactic system. If the cluster moves constantly with this velocity, it will have reached the galactic plane within fifty million years, coming from its present isolation in space



to the regions where scattered galactic stars are numerous and where all the open clusters are found.

The foregoing analysis of a single typical globular system indicates the relevancy of the investigation of clusters to general stellar problems. The factor that contributes most to knowledge of the sidereal universe naturally is that of distance, for distance is the key to the actual dimensions of a cluster and to the real luminosity of stars. We directly approach problems of even greater interest, however, when the distance is determined not only for Messier 13 but also for the 85 other globular systems that are now recorded in our catalogues. Those problems are the size of the known stellar universe, and the arrangement and relationships of its various parts.

Probably the most interesting of many results deduced from the study of the aggregate of open and globular clusters is the evidence of the insignificance of the earth, sun, and brighter stars in the general galactic system. We are impressed with the shortness of the sidereal distances commonly measured as compared with those of clusters, Cepheid variables, and star clouds. The sun, it appears, is only a yellow, dwarfish, very old star, eccentrically situated in a large moving star cluster which is itself situated still more eccentrically in an immensely larger stellar organization—that is, in the general galactic system, which appears to include practically all known objects of the stellar universe.

The details and general results of the investigation of the distances and distribution of all globular clusters cannot be mentioned here; but we may conclude and briefly summarize by stating that the study indicates that in volume the galactic system is more than a hundred thousand times as large as we formerly believed it to be. The center of the great ellipsoidal system appears to lie in the direction of the rich star clouds of Sagittarius, at a distance of at least sixty thousand light-years. Its most striking feature, besides its dimensions and probable mass, is the extensive, much flattened, mid-galactic segment, which contains open clusters, isolated stars, and nebulae in abundance, but appears to be empty of globular clusters. Apparently the globular clusters are approaching this segment from without—their radial motions, their distribution in space, and their

probable genetic relationships to open clusters support that view. It may be that the thousands of sub-organizations in the galactic system, such as open clusters, star streams, moving groups like those in Ursa Major and Taurus, wide pairs of stars of common motion, long-period visual binaries, all originate in these in-falling globular clusters; it may be, too, that the galactic system itself, which possibly is little else than a great mixture of disintegrating minor systems, owes its beginning and subsequent growth to globular clusters. But whatever its origin and destiny, it is clear that the sidereal system, as it now stands out, is a giant in mass and volume compared with the region around the sun to which we have usually confined our stellar investigations.

MOUNT WILSON OBSERVATORY,  
PASADENA, CALIF.  
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## HYDRATION AND GROWTH.\*

By D. T. MACDOUGAL.

(Read April 25, 1919.)

The studies described in the present paper are based upon the results of three methods of observation and experimentation, as follows:

(a) A comprehensive series of measurements of the variations in volume of stems, leaves and fruits have been made in which the course of growth and variations in rate have been correlated with variations in such environmental factors as temperature, humidity, water supply, etc. The records include the entire developmental period of many stems extending in some cases over a period of two years. A paper descriptive of some of this work was presented before this Society three years ago and was printed in the *Proceedings* for 1917.

(b) Attention has been directed to the determination of the composition of living matter and the manner in which its components are united or mixed in the cell. Series of analyses arranged to show not only the general character of the cell contents, but also the seasonal and developmental changes in plants have been made, in connection with the comprehensive work of Dr. H. A. Spoehr upon carbohydrate metabolism (now in press).

(c) Measurements of the hydration reactions of tracts of living cell-masses have been compared with the reactions of sections of plates of colloids made up in simulation of the composition of plants show that the water relations of the living material of the higher plants are those of a colloidal mixture consisting predominantly of pentosans, of a lesser proportion of albumin, albumin derivatives and amino-compounds and of a minor proportion of lipins, with an inevitable small amount of salts.

The components of these three groups are not mutually inter-diffusible to any extent and hence in my colloidal preparations, as

\* Abstract prepared by author from a lengthy manuscript.

well as in the protoplast, must be considered as simply mixed in an intimate manner in interlocking meshworks, foams or whatever interpretations may be given to the structures revealed by cytological technique. Living matter made up in this manner may be miscible, or immiscible, according to the nature of the pentosan or protein entering into its composition. It is obvious that the protoplasm in which the carbohydrate element is like agar would not be "soluble," while a mixture composed largely of gum arabic would go readily into suspension. Hydration as used in this paper denotes the union of water with the molecules or aggregate of molecules of substances in a colloidal condition inclusive of the action by which first definite proportions are taken up in so-called chemical combination, and also of the indefinite absorption combinations.

Growth may be defined as consisting chiefly in the hydration of colloidal material in a living condition generally accompanied by accretions to the main components as described above, although not actually necessary for the conception as the ground or fundamental structure of protoplasm might be increased by rearrangements of material already included. The later stages of increase in volume of a protoplast are coincident with the formation of denser permanent structures having the effect of increasing the relative dry weight with age or approaching maturity, a procedure which may be taken to be universal in the tissues of the higher animals, according to the researches of Donaldson, Hatai and others.

This too is currently assumed to be the case in the tissues and organs of the higher plants, but my own results include a type of growth in which this is not the case. Succulents of all kinds produce stems or leaves in which the percentage of dry weight of small young organs such as the joints of cacti, leaves of *Mesembryanthemum*, and fruits of the melon or berry type, is greater than that of mature organs or members exemplifying a category of growth especially interesting in the present connection. Succulence is due to the hypertrophy or exaggerated growth of cells in which the hexoses have been converted into pentosans, initially as a result of low water contents of the cells, the pentosans having a high capacity for water which is exerted during the remainder of the life of the cell, and it is in such organs that the relative dry weight does not increase with age.



The living matter of the plant cell includes pentosans which are to be taken as weak acids and which show only slight dissociation, and of albumins or amino-compounds, which undergo a greater hydration with increasing concentration of hydrogen ions. Hydration of the carbohydrate or pentosan constituent or protoplasm is affected in the reverse manner. The actual rate of growth of any protoplast would therefore be a resultant of the opposing action of pentosans and of albumins.

Swelling, hydration or growth of bio-colloidal masses is not however simply a matter of hydrogen ion concentration, as we have found that the hydration and swelling of pentosan-protein colloids simulating protoplasm, of tissues of living plants and of dried cell-masses, is facilitated by the amino-compounds which dissociate as bases. The greatest increases occur in concentrations of 0.01 *M* to 0.001 *M* of such substances as alanin, asparagine, glycocoll, phenyl-alanin, and ethylamine. Concurrent accelerations of growth resulting in increased dry weight and greater volume are reported by many experimenters using such substances in culture solutions. It is highly probable that bases (cations) may have some effect on hydration or growth, a matter yet to be tested.<sup>1</sup>

The essential feature of an idealized growth is the accretion or addition of water and material to the mass of colloid constituting the cell. The actual mechanism of incorporation is not easily delineated. If protoplasm consisted of a system of colloidal structures such as those of the pentosans and the proteins interwoven, but not diffusing into each other, the more solid material which lowers the surface tension to the greatest extent, having the least attraction for water-molecules, would tend to usurp the position of the surface layer. Furthermore, the solid phase, whether it be in the form of globules or in the continuous element, would tend to increase and crowd together with a lessening of the more liquid phase. This would imply that when gelatine in small proportion is mixed with agar or starch paste in the larger proportion that the carbohydrate would form both the colloidal framework or mesh, as well as the external layer

<sup>1</sup> See MacDougal and Spoehr, "The Effect of Organic Acids and their Amino-Compounds on the Hydration of Agar and on a Biocolloid," *Proc. Soc. Exper. Biol. and Med.*, 16: 33, 1918.

of the mass. In actual practice the mixtures are solidified too quickly for this to occur.

The separate colloidal masses where they do exist have, of course, definite boundary layers, as are formed wherever two colloidal phases meet. Protoplasm may not be regarded however as altogether a mechanical admixture of minute strands of material of different composition. Much of it, including the more fluid portions, must consist of molecules of carbohydrates, proteins, salts and even lipins aggregated to form submicrons in the disperse phase or in the denser more solid fibers, mesh or honeycomb of the structure. The external layer formed might well be in a sense a mosaic, but it is to be noted that no actual proof of such a condition is at hand. Both absorption or imbibition and osmosis including differentiated diffusions would be affected by the composition and relations of the two phases of the colloids in this outer layer, and it seems highly probable that an adequate interpretation of permeability will be obtained by a study of these features. Meanwhile no general agreement as to the nature of the "membrane" or its action is to be expected until many widely current assumptions are discarded. The external layer of a protoplasmic unit is in every case a product of the surface energy of the mass or systems of living material internal to it and of the medium and it has no other permanent or morphological value. Its constitution must necessarily vary widely as does that of the living protoplasm.

The experimental studies described in the present paper have been devoted chiefly to the action of protoplasmic masses in which the pentosans in colloidal combination with proteins and salts determine the volume or mass of the living material of the cell. The other soluble carbohydrates, including the hexoses, sucrose, dextrose, do not occur in the cell in such concentrations as to affect the enlargement of the protoplasmic mass directly, but in the vacuoles they may exert an osmotic effect additive to that of the amino-acids which may accumulate in these cavities. It is to the osmotic activity of these substances in the vacuoles that turgidity is due and a by no means unimportant part in the maintenance of the rigidity of organs and other features is to be ascribed to these turgor stresses and tensions. The inadequacy of osmotic phenomena and of the concep-



tion of the semi-permeable membrane to provide a mechanism for the translocation of complex material from cell to cell, and the incorporation of new material in a growing mass has long been recognized. That osmotic pressure however may play an important part in the enlargement of the plant cell may well be concluded from the fact that in the stage following the initial swelling of the embryonic cell, a large share of the increase in volume is due to the increase of the vacuoles. It would be a mistake to conclude that the vacuole is simply a sac charged with electrolytes, as these cavities invariably hold proteins and carbohydrates in a colloidal condition in which the degree of dispersion may vary widely, but still absorb water. A correct estimation of the manner in which osmosis and imbibition interlock in growth is one of the tasks demanding the immediate attention of the physiologist.

#### THE EFFECT OF ORGANIC ACIDS AND THEIR AMINO-COMPOUNDS ON GROWTH.

The accelerating effects of acids or of the hydrogen ion concentration on hydration of proteins is well known, and something of the retarding effect on the swelling of mucilages or pentosans have been described in recent papers.

The effect of bases (cations) on these processes has not yet been measured, nor has the method by which the amino-compounds act in this matter been determined.

The hydrogen ion concentration of the liquids in the plant cell remains constant within limits and in succulents examined by Jenney Hempel may be expressed by  $P_h$  3.9-7, as determined by electrometer and titration methods. The presence of the acids of which malic is the more abundant, and its combinations with such bases as potassium, sodium, calcium, magnesium, iron and aluminium makes a "buffer" by which the degree of dissociation is controlled.

In addition to this comparative stability or narrow range of the concentration of hydrogen ions, amino-compounds are invariably present, and their relative amount probably varies but little.

A series of tests were planned in which a comparison would be made possible between the action of some of the commoner organic acids and of their amino-compounds.

Two groups were chosen for the tests. Succinic acid and amino-succinic or aspartic, which are dibasic, and its amide as noted above which is monobasic, and acetic acid and amino-acetic or glycocoll, which are monobasic. Sections of plates of agar, gelatine, agar-gelatine, agar-protein and other mixtures were used. Swellings were carried out in the equable temperature chambers of the Coastal Laboratory at 15-16° C. A tabulation of the principal results is given on the following page.

The two organic acids, succinic and acetic, are seen to exert the classical effect on gelatine, the greatest hydration taking place in the higher concentrations, the effect decreasing with dilution until at 0.0004 *N* the swelling in acetic acid was scarcely greater than in distilled water. At 0.0004 *M* however the dibasic succinic acid showed a swelling less than that in distilled water, a fact which suggests a rapid solution or dispersion from the surfaces of the sections and alterations of viscosity in the mass.

Mixtures of agar (8) and gelatine (2 parts) were now tested, and the hydration in succinic at 0.00008 *M* was but 1030 per cent. as compared with 1684 per cent. in water, while acetic acid was slightly higher, 1167 per cent. A similar statement would hold for the action of these acids on agar, and for agar-protein, the hydration of water along being reached more nearly than in the agar-gelatine sections.

When we now turn to amino-succinic or aspartic acid and amino-acetic acid or glycocoll, some new relations are uncovered.

The aspartic acid (amino-succinic) appeared to exercise a notable influence on the hydration of agar within the range of its solubility. When more than this was added to the water used for solution a swelling in excess of the expectancy resulted. It was also seen that the surface of the liquid became covered with thin crystals. In all probability the solution or dispersion of some agar into the water resulted in the displacement of some of the acid with the result that the sections were actually hydrated from a solution less concentrated, giving a swelling in excess of the expectancy.

Asparagin was now applied in a series of concentrations to sections of agar of the above swelling capacity in water and it was found that hydration was actually increased or accelerated by the



HYDRATION OF AGAR, GELATINE, AGAR-GELATINE AND AGAR-OAT-PROTEIN IN ORGANIC ACIDS AND THEIR AMINO-COMPOUNDS AT 16-17° C. EXPANSION IN PERCENTAGES OF DRIED THICKNESS.

Concentration.	Succinic Acid Mol.	Aspartic Acid Mol.	Asparagin Mol.	Acetic Acid Mol.	Glycocoll Mol.
<i>Agar.</i>					
0.3	....	....	....	....	1950%
0.5	....	....	....	....	2804
0.1	....	1000%	2260%	1060%	....
0.05	1091%	827	2308	1333	....
0.01	1273	1270	2365	1560	2964
0.002	1600	1400	2440	1790	3166
0.0004	1750	1788	2720	1955	2605
0.00008	2528	2080	3250	2640	....
Water	Average:	2600%			
<i>Gelatine.</i>					
0.1	....	....	....	....	....
0.05	1200%	1500%	320%	952%	370%
0.01	700	1033	480	714	....
0.002	500	380	500	690	360
0.0004	433	340	467	643	360
Water	Average:	600%			
<i>Agar 8—Gelatine 2 Parts.</i>					
0.5	....	....	....	....	....
0.1	....	....	....	....	....
0.05	716%	910%	1485%	850%	....
0.01	860	1017	1574	850	1233%
0.002	917	1295	1608	900	1960
0.0004	1000	1667	1383	922	1767
0.00008	1030	1786	1383	1117	1420
Water	Average:	1684%		1167	1484
<i>Agar 8—Oat-protein 2 Parts.</i>					
0.5	....	....	....	500%	....
0.1	....	....	....	809	....
0.05	700%	855%	1867%	1090	1983%
0.01	864	900	2455	1255	2340
0.002	909	1670	2523	1738	3050
0.0004	1136	2500	2675	2238	3000
0.00008	2330	3050	2600	2480	....
Water	Average:	2365%			

presence of this substance. That this result did not simply appear by faulty comparisons was shown by the following replacement test.

A trio of sections which had been swelled in distilled water to a

total of 2630 per cent. and which had stood in the solution without any perceptible change for a few hours after the close of the test was now treated to a 0.01 *M* asparagin solution. The mechanical disturbance which might result from changing the liquid in the dishes was minimized by fractionization. About one third of the water was removed then the level was raised by the addition of asparagin solution and this was repeated about a half dozen times, the final result being a solution which was diluted slightly below hundredth molecular. A slow expansion began at once which continued for about 20 hours, which raised the total hydration of these sections to 2890 per cent., an increase of 230 per cent., due to the action of the asparagin on sections which had undoubtedly been reduced in mass somewhat by solution from the surfaces.

The presence of asparagin in the water in which swelling of gelatine was carried out, produced an uncertain effect by reason of supposed solution or dispersion of the gel. Neither can much be said concerning its action on agar-gelatine mixtures, except that the results show a maximum at 0.01 *M*.

When the asparagin is applied to mixtures in which the gelatine is replaced by an albumin, the results included some special reactions. Plates of agar and oat-protein were made up to contain 8 parts of the first and 2 of the last, coming down to a thickness of 0.22–0.23 mm. These swelled at 17° C. to the proportions shown in the table, which in some cases exceeded that in water. The swelling in concentrations as high as 0.01 *M* were but little below that in water.

Glycocoll has been used in many cultural tests with plants and various interpretations have been placed on its accelerative influence on growth, and its influence on swelling therefore has an unusual interest.

Thin sections of agar swelled in all glycocoll solutions less concentrated than 0.3 *M* to the amplitude attained in water and exceeded it in some cases, a fact which for the first time gives a sound basis for results in which growth was accelerated and the total increased by this compound.

Another pentosan, gum tragacanth, was dried from solutions to



form sections 0.13 mm. thick on filter paper. Swellings at 15° C. were obtained as follows:

Distilled Water.	Glycocoll.		
	0.3 M.	0.05 M.	0.01 M.
1380% .....	1382%	1077%	1462%

This gum liquefies irregularly and hence the figures show the extent of swelling before active dispersion of the mass begins.

Next a mixture of 9 parts of gelatine and 1 part tragacanth was made up at 2.5 per cent. to correspond to a similar mixture of gelatine and *Opuntia* mucilage. Swellings as follows at 15° C. were obtained:

Distilled Water.	Glycocoll		
	0.3 M.	0.05 M.	0.01 M.
1320% .....	1520%	1040%	1320%

Nothing may be concluded on the basis of these figures except that the hydration of this material reaches a stage where it goes into dispersion unevenly and in a manner which makes auxographic readings, as well as all mass or weight determinations, of doubtful value.

The above tests were repeated with *Opuntia* mucilage with the following results:

Distilled Water.	Glycocoll (15° C.).		
	0.3 M.	0.05 M.	0.01 M.
923% .....	800%	654%	600%

It is highly probable that the high relative swelling in the more concentrated solution is due to the hydrogen ion effects on the gelatine as glycocoll is known to show some dissociation in this way.

Sections consisting of 4 parts agar and 1 of gelatine which had an average thickness of .3 mm. swelled as follows at 15° C. in glycocoll.

0.3 M.	.05 M.	.01 M.	.001 M.
1550%	1233%	1960%	1767%

The average swelling of such sections in water was about 1700 per cent. and the irregularity characteristic of auxographic measurements of the action of this amino-acid is seen in the above results.

A preparation was now made in which two parts of the water soluble protein from oats was added to 8 parts of agar in a 2.5 per cent. solution of the latter. The plates dried to a thickness of .25 mm. When sections of such biocolloids were swelled in the gly-cocoll series, the results were as shown in the table, the hydrations in concentrations less than 0.01 *M* approaching and surpassing those in distilled water.

The action of acids being supposedly due to the hydrogen ion concentration, a test was made of the action of a solution in which glycocoll (amino-acetic) was added to acetic acid. Trios of surface slices of *Opuntia* which had dried to a thickness of 0.8 mm. swelled 163 per cent. in .05 *N* acetic acid and 156 per cent. in a .05 *N* solution of acetic acid and glycocoll. No especial significance can be attached to the lesser swelling in the double solution, except that no evidence as to acceleration of swelling by the addition of the amino-acid was obtained.

Next trios of sections of 8 parts agar and 2 parts gelatine 0.3 mm. in thickness were swelled in the acetic and amino-acetic solutions 0.01 *N* at 18° C. The swelling in the acetic acid alone was 1450 per cent., while that in the combined solutions was but 1300 per cent., which agreed with the previous effects in being less than in the acid alone.

Trios of sections of agar swelled 1875 per cent. in a 0.01 *N* solution of acetic acid at 18° C., while a combined solution of equivalent molecular concentration showed a swelling of 1750 per cent.

There now remained the test with living tissues. Some joints of *Opuntia blakeana* of 1918 which had been brought from Tucson two months earlier and had laid on the table with the result that they had lost much water but were still alive, were used for this test. A trio of sections with an average thickness of 6 mm. swelled 60 per cent. in the hundredth normal acetic acid, while a similar trio which measured 5.5 mm. on the average swelled but 45.5 per cent. in the combined acetic-glycocoll solution. A second feature distinguished the two reactions, the swelling in the acetic being continuous and approaching zero during the 20 hours of measurement, while in the combined solution full expansion was reached in 4 hours after which a shrinkage resulted in a loss of nearly 5 per cent.



A return was made to the biocolloidal mixtures and trios of sections of agar 8 parts and oat protein 2 parts with a thickness of .22 mm. were swelled at 18° C. The hydration swelling in the hundredth normal acetic acid gave an increase of 1318 per cent., while an equinormal solution of the acetic acid and glyocoll gave a swelling of 1605 per cent. This test is the only one of the series in which the addition of glyocoll to the acetic acid enhances imbibition.

An additional test was made in which equal amounts of glyocoll and acetic acid were brought together at a concentration of 0.001 *M* on agar-oat protein sections as above. The swelling in the acetic acid was 2681 per cent. or about the same as that possible in distilled water (2630 per cent.) while the swelling in the combined solution was slightly less, being 2570 per cent., a difference which is without special significance in this case, as it is near the limit of instrumental error or might have been caused by brief temperature variations.

The positive action of amino-compounds in affecting hydration is well demonstrated by the above facts. These effects are not coincident with the action of solutions offering the greatest hydrogen ion concentration, or at any point in which an optimum of such action might be assumed. The actual maximal hydrations in amino-compounds take place in reality in attenuated solutions (0.1 *M* to 0.00008 *M*), but the nature of the action has not yet been determined.

#### THE TEMPERATURE FACTOR IN GROWTH.

If growth were dependent in the main upon any reaction or upon a chain of consequent transformations the influence of temperature upon the rate and course might be readily and definitely established. Many authors have assumed such a state of affairs.

Growth however is an interlocking meshwork of reactions and a rise of temperature through the ordinary range from 5° C. to 30° C. may and generally does pass the point at which one or more of the reactions passes the range of its accelerating effect, and in any further rise becomes an inhibition. Such results are to be found, for example, in the action of hydrogen ions or in respiration residues. The following experiments may serve to illustrate this matter.

The petioles of some young plants of a *Solanum* hybrid in the glass house at Tucson were available on April 21, 1918. Trios of sections were placed in distilled water and acids at 18° and 38° C. with results as follows:

	Distilled Water.	Hundredth Normal Citric Acid.
18° C. ....	4.2%	4.2%
38° C. ....	11.8	2.6

The swelling in distilled water was nearly three times as great at the higher temperature, while in the acid solution a retardation took place which limited the total at the higher temperature to something over a half that possible at the lower point. The total swelling in acid at the lower temperature occupied an hour and at the higher temperature it was a matter of ten or fifteen minutes. A similar speeding up of imbibition in water was observed. The total capacity at the lower temperature was not reached for 8 or 10 hours, while at the higher it was something under 2 hours.

Plants of *Phaseolus* which formed the experimental material for measuring the growth of pods and seeds bore some pods in which the beans were nearly mature. Pods of the same stage of development as one which was under the auxograph for recording daily changes were opened and the unripe beans removed. The ends were cut away, the outer coat removed; the remainder of each cotyledon made on section of which three were taken from separate pods for swelling. The average thickness was 3.2 to 3.4 mm. and the swellings were as follows:

	Distilled Water.	Hundredth Normal Citric Acid.
38° C. ....	{ a....14 % b.... 8	{ a....11 % b.... 9.7
18° C. ....	{ a.... 9.6 b....11.7	{ a.... 6.6 b.... 4.4

The higher temperature to which *a* was subjected appears to be above the point at which maximum absorption or imbibition takes place in distilled water as the swelling was 30 per cent. less than at the point below. The retarding effect is much more marked in the acid solution, however, as the reduction of the total capacity below that shown at 18° C. amounted to 40 per cent.



The material in series *b* taken at a later date and with seeds which seemed to be more nearly mature, showed an increase in swelling in distilled water of about 45 per cent. over the total at the lower temperature, while the swelling in acid was less than half that at 18° C. The average of the two series is such that the swelling in distilled water is nearly the same at both temperatures, while in acid the average at 18° C. is 10.4 per cent., which is nearly double that at 38° C. at which point the hydration capacity seems to be invariably lower than at the lower temperature. These averages represent a total of six cotyledons each.

A final test of variations in temperature upon material in an acidified condition was made with dried sections of *Opuntia*. These sections were made by slicing away the chlorophyllous layer from one side of the flat joint and drying the remainder in the desiccator and in sheets of blotting paper in such manner that buckling and crumpling was prevented. After all of these precautions were taken, however, the measurement of the sections was subject to some error due to the fact that the fibrovascular strands remaining would increase the thickness under the calipers without reacting in due proportion to the action of the swelling agent. A wide range of figures was obtained, but it was apparent that a rise in temperature did not have an effect on material in acid equivalent to that in distilled water, as will be apparent from the following measurements obtained from sections which were .43 to .46 mm. in thickness.

	Distilled Water.	Swelling in Hundredth Normal Citric Acid.
18° C. ....	315%	360%
	385	430
	486	460
Average ....	395%	417%
28° C. ....	453	460
38° C. ....	500	477
	413	400
Average ....	457	439

The increase in swelling in distilled water is seen to be about twice that in the acid in the rise from 18° C. to 38° C. The influence which the condition in question may exert on the rate of growth is obvious. Thus the course of enlargement of an organ or

of a cell-mass in so far as this consists in hydration may vary widely in the first instance because of the residual acids in the colloids and the balance or accumulation of this will in turn depend upon the effect of the enzymatic or respiratory processes in metabolism. Thus a rise of 10 degrees from the customary morning temperature of 15° C. which has been encountered in so many of these experiments, would result in an acceleration of growth largely determined by the state of acidosis of the plant. A rise from the same temperature later in the day or under other conditions of illumination would necessarily have a different result. An extension of the attempts to bring rates of growth into a figure or formula, therefore, would be a forced application of knowledge of one process to a complex of activities in which any change in temperature might set up opposed alterations. In consequence of this fact, the coefficient of variation for 10° C. is seen to vary from one to seven in various organisms.

The capacity for hydration and growth is a resultant of the composition and proportions of the principal components of the living matter and the relations of the phases in which they occur, modified by the "nutrient" salts absorbed in its structure, and by the products of unceasing metabolic changes, especially the transformations which are comprehended in respiration and which carry compounds through a stage in which acids are formed. These features as influenced by temperature determine the rate, daily course and total expansion in growth. In addition, a certain amount of material is lost from the plant in the form of carbon dioxid, and as has been emphasized on the preceding pages, the surface loss of water may overbalance absorption. The rate, course, and amount of growth is therefore affected by many agencies and includes multiple interlocking reactions.

#### WATER-CONTENT, DRY WEIGHT AND OTHER GENERAL CONSIDERATIONS.

Two different types of organs or shoots with respect to the variations in the water-content and dry weight are recognizable in the material which has served for studies in growth as described in this paper and in the work of other writers. The commoner types



of woody stems, thin leaves and the organs of the greater number of the higher plants undergo a development which terminates in a mature stage in which the proportion of solid material is very much higher than that found in younger material. A parallel procedure is the prevalent one in the tissues of the higher animals. Thus by way of illustration, Donaldson found that the proportion of water in the bodies of mammals diminishes with age, and Hatai has shown that the percentage of water is an indicator of phases of chemical alteration in the composition of the body.<sup>1</sup>

Growth and differentiation of cell-masses into specialized tissues is not inseparably connected with increases in dry weight, however, as has been demonstrated by studies of the growth of frog larvae in the earlier stages,<sup>2</sup> and it is highly probable that similar phenomena are prevalent in the fleshy fungi and other lower forms of plants.

The distinction between the two kinds of growth has not been made previously in studies of plants and the matter was finally taken into consideration in the experiments late in 1918.

Etiolated plants furnish examples of growth with a small increase in proportionate dry weight, but chief interest attaches to plants which normally show such action, and the most striking illustrations are to be furnished by the organs of succulent plants and by fruits. The relative amounts of solid material in the flattened joints of *Opuntia* does not increase with the course of development toward maturity, and joints which have reached full size may contain over 91 per cent. of water. Secondary thickening, especially that which results from branching and the development of additional fibrovascular tissue, may cause an added amount to be formed. The proportion of dried material and water in the leaves of *Mesembryanthemum* does not vary greatly with age. These and probably all succulent forms are characterized by an exaggerated production of mucilages or pentosans, and have certain implied cycles of metabolism includ-

<sup>1</sup> Donaldson, H., "The Relation of Myelin to the Loss of Water in the Mammalian Nervous System with Advancing Age," *Proc. Nat. Acad. Sc.*, 2: 350. 1916.

Hatai, S., "Changes in the Composition of the Entire Body of the Albino Rat during the Life Span," *Amer. Jour. of Anat.*, 1: 23. 1917.

<sup>2</sup> Ostwald, W., "Ueber die zeitlichen Eigenschaften der Entwicklungsvorgänge," p. 49. 1908.

ing an incomplete type of respiration which leaves large acid residues. The total acidity of the cell-masses may vary greatly during development and during the course of a day, and the actual acidity or hydrogen ion concentration of the sap resulting from the buffer situation may also show a marked variation, but within much narrower limits.

Although the development and maturation of fruits such as berries obviously includes a growth in which the total effect is one of practical maintenance or increase in the water-content, studies of their growth seems to be lacking. It was therefore planned to arrange a final series of experiments in which the enlargement of fruits with increasing dry weight and others with low relative dry weights should be measured. The walnut was taken to represent a structure with accumulating solid matter, and the tomato for the other type.

The walnut consists of a thick fleshy exocarp and a heavy endocarp which finally becomes hard and bony with the deposition of anhydrous wall material. The enclosed embryo also accumulates a large amount of condensed food-material. The tomato is a large globose berry in which deposition and thickening is confined to the small hard seeds. The greater part of the fruit is a fleshy pulp, which becomes more highly watery as progress is made toward maturity.

Nuts of *Juglans californica* var. *quercina* Babcock, of various sizes from 3 mm. in diameter to that approaching maturity were on two trees in the garden at Carmel in June, 1918. Suitable supports being provided, the bearing lever of an auxograph was rested as lightly on the young nuts as was consistent with a clear record, and temperatures were taken by thin thermometers thrust into similar nuts or into young stems near the preparation. Fifteen nuts were measured for periods of two or three days or for as long as two months in the case of No. 10.

Coincidentally with the measurements an effort was made to determine the degree of saturation or hydration of the stems on which the nuts were borne. A well defined "negative" pressure was detected in the basal branches of *Juglans major* which was growing near the experimental tree. A basal branch 1.2 meters from the trunk gave a dry looking surface when it was cut off.



A section of a similar branch about 8 mm. in thickness and 42 cm. long was cut away from another basal branch of the tree, the end of the detached portion quickly sealed with vaseline and when all was in readiness the tip was excised and the cut thrust into water to ascertain the actual deficiency in this portion. 14 hours later a total of 6 c.c. of water had been absorbed and 24 hours later 8.5 c.c., which was a practical saturation, at a temperature of 18° to 20° C. The volume of the branch proved to be 35 c.c. so that the amount of water absorbed was 24 per cent. of the total.

Sections of young internodes of *Juglans californica quercina* which had an average diameter of about 2.5 mm. were swelled in solutions as below, then dried and swelled again with results as below at 16° C.

Water.	Citric Acid 0.01 Normal.	Potass. Hydrate 0.01 M.	Potass. Nitrate 0.01 M.
<i>Fresh—living.</i>			
10%	14%	13.2%	12%
<i>After Drying.</i>			
34	34	34	32
(On basis of original thickness.)			

The unsatisfied capacity of these sections taken from young terminal internodes was comparatively great, doubtless due in part to the constant drain of the active leaves they bore. The older wood including that formed the previous year showed an absorptive capacity of 22 per cent. in water. Now it is from these older internodes that the nuts arise.

The nuts were highly turgid, exuded sap when cut into, and hence must have had a colloidal composition which acted to withdraw water from the stems which contained a much lower percentage of water. The soil was low in moisture content at this time, as it had been four to five months since the rains.

Tests of nuts 8 to 10 mm. in thickness from which tangential slices had been removed to give a uniform thickness of 7.5 mm. were made in July, and these swelled at temperature of 17 to 30° C. in solutions as follows:

Distilled Water.	Citric Acid, .01 M.	Potass. Hydrate, .01 M.	Potass. Nitrate, .01 M.
1.5%	1.8%	1.4%	2%

A useful conception of the hydration conditions in the stems and fruits may be formed, if due weight is given to the measurements cited above. The woody branches of the previous year, on which both the leafy green twigs and those bearing the nuts are borne, had a relatively large deficiency in water so that sections a few centimeters long absorbed about 20–25 per cent. of their volume of distilled water in 24 hours at 20° C. No swelling test was made, but it is obvious that an enlargement of only a small fraction ought to be shown by this or any branch with a mature woody cylinder. The active green twigs still in a state of elongation arising from these branches had a swelling capacity of 10 per cent. The growing nuts arising from the drier stems exuded water from cut surfaces, the cotyledons being sacs of watery fluid, in contrast to the dry appearance of sections of the youngest internodes, and showed a swelling of less than 2 per cent. and soon shrunk when placed in a cylinder of distilled water after being cut in halves. In a system of this kind any alteration of the conditions which would facilitate transpiration would have a differential effect on the older stems, the green leafy twigs and the fruits. The loss from the stems would be affected least since the bark would effectually prevent any notable increase in evaporation from the relatively dry woody tissues. The loss from the leafy twigs would of course tend to become greater and the deficit in both leaves and twigs would be increased and their absorbing power correspondingly increased. The outer integument of the nuts being still in an embryonic condition and being highly hydrated the loss would reach a maximum rate with the daily effect of causing a cancellation of enlargement beginning mid-forenoon at 20–22° C. and continuing until mid-afternoon when a fall in temperature brought transpiration to a rate below that of accession from the stem.

A large percentage of the nuts which were placed under the auxograph lever were cut off at various stages of development by abscission of the stalk. The inciting causes of the actual anatomical change which cause the abscission lie outside the scope of this article. It was noted however that it was preceded by a period in which the nut showed a shrinkage by day in the higher temperatures and lessened humidity, alternating with equalizing enlargements at



nights. Finally an abrupt rapid and continuous shrinkage resulted in the separation of the stalk.

The general features of growth of these nuts may be illustrated by a résumé of history of No. 10, which was under continuous observation from July 15 to September 9, 1918, during which period of 56 days its diameter increased from 16 mm. to 26.5 mm. Of this 2.25 mm. was gained in the first five days of cool foggy weather. This effect was confirmed by the fact that a cessation or retardation occurred at midday and was most pronounced on hot sunny days, suggesting a direct water-loss. In the week ending July 29, the total growth was an increase of 1.7 mm. This period was characterized by heavy fogs and mists in the forenoon, both the amount of shrinkage and rate of increase being lessened—an equalization to be ascribed in part to approaching maturity. The temperature taken from a thermometer thrust in a young branch of the thickness of the nut ranged from 13 to 22° C. The completion of the record of No. 10 was followed by cutting of the branch bearing it at a distance of 30 cm. placing excised end in water and arranging the entire preparation in the dark room at 17° C. with the nut under the bearing lever of the auxograph. Swelling continued for about 20 hours after which shrinkage began which rapidly accelerated.

The general features of growth were also well illustrated by the following notes on No. 15, which was brought under observation when it was about 15 mm. in diameter and put under an auxograph amplifying 45 on August 3. Great daily variations in size with a net total increase were displayed every day. Actual enlargement could be detected between noon and 2 o'clock which continued until 8 or 10 the following morning, depending upon the sunshine. If the sun rose clear, shrinkage began immediately. If the morning was foggy, it would be delayed, but the increase in thickness was rapid, being mostly accomplished in 2 hours. Minor variations in this general procedure might be brought about from the shade of clouds, especially noticeable at noonday August 6 and to be seen at other times (see Fig. 1).

It is to be seen from the above that the fruit of the walnut in an environment favorable to its development exhibits daily variations in growth clearly attributable to the balance between transpiration

and absorption. The nut in a growing condition has a high water content, and a small unsatisfied capacity, but its supply from the relatively dry stems must come slowly, so slowly that any marked increase in transpiration would overbalance absorption in the nut and result in cessation of enlargement or even shrinkage.<sup>3</sup>

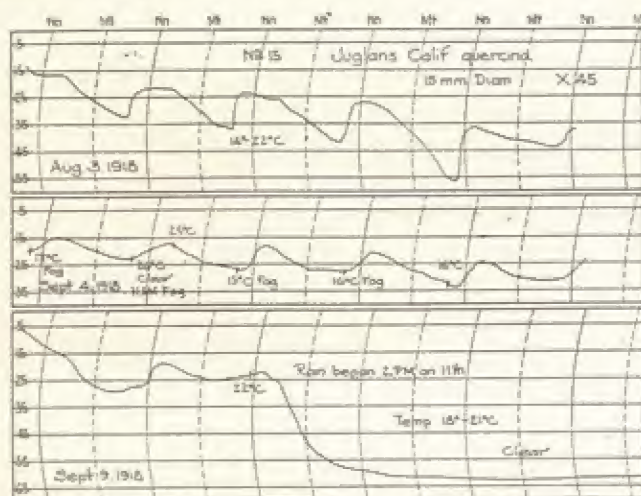


FIG. 1. Tracings of auxographic record of walnut (No. 15) during three weeks. Variations are amplified forty-five times and the downward movement of pen signifies enlargement. The scale is numbered in millimeters. Shrinkage during the midday period lessened by fogs and acceleration in growth by the humidity and increased water supply from rain are among the more striking features.

Such retardation or apparent cancellation of growth by rapid or excessive water-loss has already been discussed in connection with the presentation of my original results dealing with the growth of *Opuntia*. Recent exemplification of this action in *Cestrum nocturnum* has been described by Brown and Trelease.<sup>4</sup>

The fruit of the tomato (*Lycopersicum*) presents similar features of behavior. The proportion of solid matter in young fruits

<sup>3</sup> MacDougal, D. T., "Reversible Changes of Form in Succulents." Report Dept. Bot. Res. Carnegie Inst. of Wash. No. 14, p. 71. 1915.

<sup>4</sup> Brown and Trelease, "Alternate Shrinkage and Elongation of Growing Stems of *Cestrum nocturnum*," *Philip. Jour. of Science*, 13: No. 6. Bot. p. 353. November, 1918.



was greater than in those approaching maturity, representing the extreme of this type. Four fruits less than a week old, with radial diameters of 14, 16, 17 and 18 mm. were found to weigh 14.650 grams. These were fragmented and placed in a beaker on a water bath at about 100° C. for 48 hours, at which time the dry material remaining was 1.90 grams. From this it is to be seen that the young fruit contained 87 per cent. of water and 13 per cent. of dry material. A mature fruit of the same kind as those measured taken September 10 from a ranch near the Coastal Laboratory was 46 mm. in axial diameter and 58 mm. in radial diameter and weighed 93.050 grams. This was dried over a water bath for 2 days, at which time 8.400 grams remained. From this it is to be seen that the ripe fruit contained 91 per cent. of water and 9 per cent. of dry material. (See Anderson, S. P., "The Grand Period of Growth in a Fruit of *Cucurbita pepo* Determined by Weight," *Minn. Bot. Stud.*, 1: 238, 1894-98; and MacDougal "Practical Text-book of Plant Physiology, pp. 293, 294, 1918, New York.)

A number of plants of the tomato were grown in suitable boxes of soil at a ranch in the Carmel valley, and were in such a stage of development that young fruits were available at the Coastal Laboratory in August, 1918.

Six plants in all were used and continuous records from fruits of an axial diameter of 3 to 4 mm. to maturity at 50 to 55 mm. were obtained. The fruits were oblate-spheroid in form and the auxograph was arranged to register increase in diameter nearly parallel to the axis in some cases and radially or at right angles to it in others. In addition to the other advantageous features of this material their regular form and mode of growth made it possible to use the variations in diameter as a basis for calculating the changes in volume of the fruits taken as spheres.

Temperatures were taken by thrusting the thin bulbs of the small thermometers into fruits near the one under measurement. The development of such fruits was but little affected by this wounding and the thermometer remained firmly in place as in the fleshy joints of *Opuntia*, in the measurement of which this method was first practised. The preparations stood in a well-ventilated glass house and the soil around the roots was kept moist in accordance with the

cultural requirements of these plants. The results may be best set forth by the description of the action of the several fruits measured.

No. 1 was placed in the greenhouse and a fruit 29 mm. in diameter was fixed on a block of hard cork in such position that it gave a radial bearing to the auxograph which was set to amplify changes in volume by 5, on August 9. The record was kept continuously until September 18, at which time the radial diameter of the fruit was 51.5 mm. The fruit was turning yellow on September 16 and was showing fluctuations in volume comparable to those in No. 2, with which it was run in close comparison and under almost exactly the same conditions of moisture and temperature as recorded.

No. 2 was adjusted to the auxograph in the greenhouse on August 9 in such manner as to give modifications of the axial diameter, which at this time was about 27 mm. The record was continuous until September 18, at which time the diameter was 50.5 mm. This fruit like No. 1 was beginning to turn yellow on September 16.

No. 3, 10 mm. in diameter, was adjusted to the auxograph to record variations in radial diameter on August 21, and a record was kept continuously with frequent notations of temperature and sunshine, etc. It is to be noted that 1, 2 and 3 were under equable temperatures, 19 to 20° C., and high relative humidity during the rainfall of September 11 and 12.

The fact that the greatest increase in growth occurs in fruits at diameters between 16 to 25 mm. in diameter, before half the final size is reached is a point to which we shall recur in the discussion of growth in terms of volume. Thus in No. 3 the increases in thickness weekly were as follows: 6 mm., 6.3 mm., 2.5 mm., 3.5 mm.

If this method be followed it would at once be obvious that while the rate of increase in diameter would be a direct measurement yet as the fruit increases as a globe the actual material added could be regarded as a shell on this globe. The rate in terms of volume would therefore be the amount of this shell to be calculated by finding the difference between the initial volume, and the volume at the end of each period by the formula  $Pi r - Pi R$  in which  $r$  = the new radius and  $R$  the initial radius. The rate by direct measurement of diameter and by volume increases may be compared as below.



Average daily rate of growth measured as increase in diameter was as follows for periods beginning as follows:

Aug. 9th.	Aug. 16th.	Aug. 21st.	Aug. 28th.	Sept. 4th.	Sept. 11th.
1.7 mm.	1.1 mm.	0.7 mm.	0.4 mm.	0.28 mm.	0.17 mm.

Average daily rate of increase in volume:

1,953 cu. mm.	1,885 cu. mm.	1,548 cu. mm.	1,036 cu. mm.	732 cu. mm.	521 cu. mm.
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The rate on September 11 by direct measurement would appear to be one tenth that of a month earlier, yet actually water and new material was being added at a rate equivalent to one fourth of the earlier rate. The radial proportions would make the rate on August 21 not much more than 40 per cent. of the rate on August 9, while the increase in volume was over 96 per cent. The rate in the week beginning August 28 would appear to be less than a fourth that by direct measurement on August 9, yet actually the increment of water and material is more than half that in the younger stage and smaller size.

A second plant with the auxograph bearing arranged to take axial variations in the fruits which measured 33 mm. was arranged to run concurrently with No. 1 and under identical temperature and conditions of moisture. The daily rates of increase in diameter were as follows for the periods beginning:

Aug. 9th.	Aug. 16th.	Aug. 21st.	Aug. 28th.	Sept. 4th.	Sept. 11th.
0.95 mm.	0.7 mm.	0.56 mm.	0.3 mm.	0.2 mm.	0.2 mm.

Daily rates in terms of volume:

1,563 cu. mm.	1,388 cu. mm.	1,274 cu. mm.	949 cu. mm.	380 cu. mm.	420 cu. mm.
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Here again the actual course of growth as calculated in terms of volume shows that simple measurements of the thickness do not express the real values in growth in such organs.

The third test was made on a fruit taken at a much earlier stage at a diameter of 16 mm. with a transverse or radial bearing, the temperature and moisture conditions being similar to those of 1 and 2. The daily rate of increase was as follows for the weeks beginning on the following dates:

Aug. 21st.	Aug. 28th.	Sept. 4th.	Sept. 11.	Sept. 18th.	Sept. 25th.
.85 mm.	.85 mm.	.64 mm.	8. mm.	.3 mm.	.37 mm.

Daily rate in volume:

537 cu. mm.	851 cu. mm.	885 cu. mm.	1,643 cu. mm.	594 cu. mm.	662 cu. mm.
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The actual volume of this fruit at the close of the experiment was approximately 2,200 cu. mm. and its growth had been followed for a period of 40 days. It is notable that in the earlier stage in the advance of the fruit from 20 to 26 mm. in diameter that while the increase of the diameter seems constant yet the actual accession of material is very much greater. Then in further development the average increment to the diameter was smaller, yet the actual accession of material was greater. Following this the rate falling from 0.8 to 0.3 mm. daily the accession decreases less than half.

The record of growth of No. 3 shows beyond question the effect of transpiration and water loss on growth. As the daily temperatures of the fruits rose from 12° C. and 14° C. to 26° C. and 28° C., acceleration ensued up to a point where the rise caused a water loss overbalancing the gain by hydration. Higher temperatures therefore did not facilitate or accelerate growth unless accompanied by high relative humidity. Thus the highest are those of midday and afternoon, with fog or showers. This is especially marked on

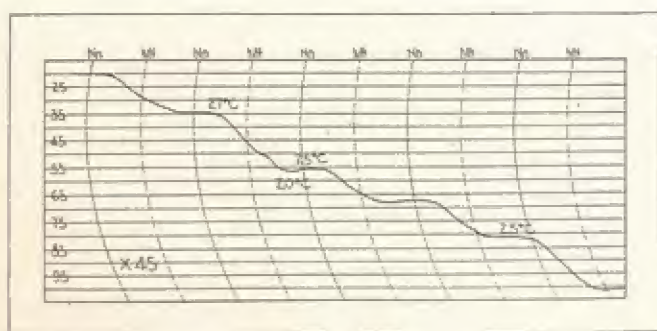


FIG. 2. Auxograph tracing of variations in volume of fruit of hybrid *solanum*. Downward course of line denotes enlargement amplified 45 times. The scale is numbered in millimeters. Midday temperatures are given.

the record of September 10, 11, 12 and 13, in which a 50-hour rainy period was anticipated and followed by high humidity. It was not possible to increase the water supply by watering the soil around the roots in such manner as to cancel the midday shrinkage or slackening in growth. One especially striking effect is that in which the rise in temperature consequent upon the cessation of the rain from



20 to 25° C. at 3 P.M. was followed by a lessened rate of growth, and on the cloudy days was uniformly high. Similar effects were exhibited by a small fruit of a potato in a greenhouse at Tucson in May, 1918.

The water deficit of the stems as measured by swelling includes that of the entire structure. The fruits however receive their supply through special conduits which sustain only a mechanical relation to the other parts of the stem which may be active in its swelling. Such non-conducting tissues of course draw their supply from this system of conduits also, but it is highly probable that the disproportion between the water content of the fruit and of the tracts in the stem from which it receives its supply is not so great as might be indicated by the measurements given. The hydration capacity of the fruits would be the resultant of many factors including the pentosan-protein ratio, the hydrogen ion concentration, the action of salts and the effect of the amino-compounds.

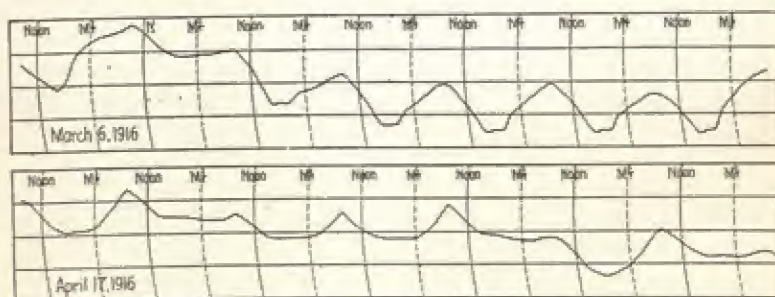


FIG. 3. Tracings of auxographic records of *Opuntia discata* during two weeks of secondary growth. Downward course of the pen denotes enlargement amplified 45 times. The scale is in centimeters. The shrinkage at night is greater in some instances than the enlargement of the preceding day.

The balance between water-loss and the gain by absorption is so delicate in the fruits the action of which was measured, and in many stems that increased humidity may be followed by accelerated growth, while a rise of ten to fifteen degrees in air temperature may check enlargement by increasing water-loss and it is also taken into account that the consequent rise in temperature of the growing stem may actually lessen the water-holding capacity of the biocolloids which make up living matter.

It would be unwise to assume, however, that the general procedure followed by the walnut, tomato and by some green stems, is universal.

The growth of the flat joints of *Opuntia* which were described before this Society in April, 1917, presents many features different to the above, and some tracings of the growth record of *Opuntia discata* for three weeks are shown in figure 3.

Enlargement (denoted by a downward course of the recording pen) begins in the morning and continues with the rising temperature until mid-afternoon, then slows down and shrinkage sets in which continues through the night. Such shrinkage must inevitably accompany and result from excessive water-loss, and in confirmation it is found that the cacti show the greatest transpiration at night, at which time the acidity rises until it is ten times as great as in the daytime. The disintegration of this by light and higher temperatures increases the imbibition capacity of the cells known to be high in pentosans and a swelling or growth in the daytime results, producing a growth record almost exactly in reverse of that of the walnut and tomato.

The rate, course and amount of growth are at all times a resultant of agencies which affect water-loss, hydration capacity, respiration and its residues and other features of metabolism.

The procedure in transpiration from the surfaces of a growing organ may be such that the maximum loss partly masking growth, may for example occur in the cacti at night, while it comes in the midday period in the commoner types. The swelling or hydration capacity of any plasmatic mass which determines its capacity for growth or enlargement depends in the main on the mucilages or pentosans present and their amount relative to the proteins, the character of which also affects growth.

The biocolloids of the plant show a degree of swelling in water greater than that in solutions containing free hydrogen ions, so that growth generally is most rapid in cell solutions near the neutral point. In modification of this last statement, it is to be pointed out that maximum swelling effects may result from the action of some of the amino-acids.

Rises in temperature within the range ordinarily associated with



growth may result in lessened swellings or hydrations, a result to be connected directly with certain fluctuations in the growth rate.

Succulent stems, leaves and fruits may show growth in which development or age is not accompanied by an increase of relative dry weight. In some of these structures, such as the tomato, it is possible to analyze the auxographic record and determine the actual total accretion of material in any stage of development. The graph plotted from such data does not follow the contours of a figure plotted from the variations in thickness or diameter, the chief difference being that the maximum comes at a later period.

## SOME CONSIDERATIONS ON THE BALLISTICS OF A GUN OF SEVENTY-FIVE-MILE RANGE.<sup>1</sup>

BY ARTHUR GORDON WEBSTER, PH.D., SC.D., LL.D.

(*Read April 20, 1918. Received May 2, 1919.*)

On the afternoon of March 23, 1918, the civilized world was astounded by the news that the Germans were bombarding Paris. Inasmuch as it was known that the nearest point at which the German lines approached Paris was over seventy miles distant, curiosity was universal as to how this result was accomplished, and the most unlikely and absurd hypotheses were suggested.

The writer, among others, was asked whether or not the result was likely to be due to an aerial torpedo. The next day revealed the truth, which was, simply, that the Germans had really built a gun which carried a projectile this hitherto unheard-of distance.

It has since been determined that the gun is situated in the Forest of St. Gobain in the neighborhood of Laon, at a distance of about 120 kilometers or seventy miles.

At this distance the curvature of the earth causes one end of such a line to be about a half mile below the horizon at the other end, so that it is impossible to see the target from the gun or vice versa; there being no mountains of any such height in the whole region, visual aiming would be quite out of the question.

I wish, first, to call the attention not only to the remarkable ballistic achievement of the Germans in so far surpassing previous ranges but also to the unique opportunity possessed. It is obvious that precision of aim at such a distance is well-nigh impossible and that the only hope of effecting any damage lies in the possession of a very large and valuable target. Little has been allowed to come through the cable as to the damage done by these long-range shots, but enough has been learned in order to see their terrible potential-

<sup>1</sup> Contribution from the Ballistic Institute, Clark University, No. 2.



ity. I shall remind you by a few lantern slides of the concentration of monuments of civilization to such a degree as probably exists nowhere else in the world.

The gun was obviously aimed to strike the Cathedral of Notre Dame, cathedrals being the German specialty in this war. The church in which eighty people were killed on Good Friday is easily identified as the church of St. Gervais, which is across the street from the Hotel de Ville, the slides of which shown are taken from the top of that church. Other objects nearly in the line of the "axe" are the Louvre, the Sorbonne, the Pantheon, the Bon Marché (a department store) ; I will not fatigue you with others.

Even if the so-called ellipse of dispersion should be very large it is easily seen that, if the shot should fall anywhere within a circle of perhaps twenty-five miles in diameter, the moral effect would be very great.

The longest previous range used during the war was about twenty-two miles with the gun with which the Germans bombarded Dunkirk. In an article in *Nature*, March 28, 1918, which I have just seen this morning, my friend Sir George Greenhill, the author of the article on Ballistics in the *Encyclopedia Britannica*, says:

"In the language of sport the German gunner has 'wiped the eye' of our artillery experts and defied all the timid preconceived notions of our old-fashioned traditions. The Jubilee long-range artillery experiments of 30 years ago were considered the *ne plus ultra* of our authorities, and we were stopped at that as they were declared of no military value. Today we have the arrears to make up of those years of delay, but the Germans watched our experiments with great interest, resumed them where we had left off and carried the idea forward until it has culminated today in his latest achievement of artillery of a gun to fire 75 miles and bombard Paris from the frontier."

The Jubilee gun, referred to, fired a shell weighing 380 pounds at an elevation of  $40^{\circ}$  with a muzzle velocity of 2,400 feet per second, giving a range of 22,000 yards or  $12\frac{1}{2}$  miles.<sup>2</sup>

<sup>2</sup> It is a singular coincidence that as I left my laboratory to attend the meeting of the American Philosophical Society I remarked to my assistant, "Nothing is likely to 'queer' this paper except the fact that Sir George Greenhill may have calculated the trajectory and published it in *Nature*." As I entered the room, the Secretary, Dr. Hays, called my attention to Sir George's paper and I was greatly relieved to find that it contained no figures of the trajectory.

Inasmuch as the only thing that has made possible this great ballistic achievement is the taking advantage of the decrease in resistance due to the decreasing density of the air in high altitudes, it is first necessary to make some assumptions as to the law of decrease with the height. I have here assumed that the temperature is constant, giving the isothermal law of Laplace. I accordingly put

$$(1) \quad \delta = \delta_0 e^{-ky},$$

where  $\delta_0 = 1.2932 \text{ kg./meter}^3$ , and  $k$  is equal to .1251, the altitude  $y$  being expressed in kilometers. As the shot rises to a height of about forty kilometers, or twenty-five miles, this results in a diminution of density of about sixteen times. While it is true that for the upper part of the trajectory the form is practically that of the parabola as investigated by Gallileo for the vacuum, it is by no means true, as certain discussions that I have seen would seem to indicate, that there is a region about two miles high at which the effect of the atmosphere suddenly stops.

The second thing that must be known is the so-called ballistic coefficient of the projectile, involving its mass and diameter, the resistance of the air being supposed to be proportional to the square of the diameter while the acceleration is inversely proportional to the mass.

For lack of sufficient information at the time that this paper was prepared, it was assumed that the mass of the projectile was 300 kilograms and its diameter twenty-two centimeters, or eight and one half inches. It is also necessary to know the form factor, which depends upon the sharpness of the projectile. In the calculations made here the number .9, which is that of old-fashioned, rather blunt projectiles, is used. As, however, reports on the shell have shown that it is furnished with a long pointed cap of sheet metal, the form factor should be considerably reduced. If, however, we take a mass of 180 kilograms, or 396.8 pounds, the results given here will be exact if we assume a form factor of .54, which is undoubtedly much nearer the correct value. Finally, if we assume the mass to be 120 kilograms, this will give the same trajectory with a form factor of .36, which is smaller than that of any shot with which I am acquainted.



The method of calculation is as follows: The first approximation by successive arcs indicated by Gen. Siacci is used. The distance of 120 kilometers is divided into twelve equal parts, and the chord is drawn, making use of the velocity obtained, at the end of the preceding chord. We make use of the familiar equations of ballistics,

$$(2) \quad ds = \rho d\theta,$$

$$(3) \quad v = \frac{ds}{dt},$$

$$(4) \quad a_n = v^2/\rho = -g \cos \theta,$$

$$(5) \quad \frac{dv_x}{dt} = -cf(v),$$

in the last of which, which is the only dynamical equation involved, we put

$$(6) \quad dt = -\frac{v d\theta}{g \cos \theta}, \quad \frac{d(v \cos \theta)}{d\theta} = \frac{c}{g} vf(v).$$

Instead of differentials we use finite differences. The table shows the computation required for Curve 2, Fig. 4.

COMPUTATION FOR CURVE 2

$r$ No.	$V_r$	$V_r^2$	$\theta_r$ DEG.	$v^2 \cos^2 \theta$	$\Delta y$	$\Delta \theta$ DEG.	$\Delta \theta_s$ DEG.	$\bar{\theta}$	$\frac{V_{x0} - V_x}{g \cos \theta}$	$\Delta V_x$	$\frac{\Delta t}{\text{SEC.}}$	$Dx$	$V_x - \Delta V_x$	$\cos \theta_{r+1}$	$V_{r+1}$
1	1200	144.10	92°	640.10	765	3.3°	.038	6.10°	100	128.3	12.5	862	661.7	.600	1002.0
2	1002	100.4	48.7	439	1120	5.5	.097	16	40	37.5	13.1	282	624.2	.729	836.5
3	805.5	744	43.2	389	1260	7.7	.133	23.5	12	12.2	16.0	105.3	611.0	.814	749.9
4	749	561	35.5	373	1310	10.0	.175	32.5	5.5	6.88	16.35	50.3	604.1	.900	609.0
5	609	447	25.5	303	1340	12.55	.219	37.0	2.0	2.83	16.35	23.3	601.3	.974	617.0
6	617	380	12.0	380	1360	14.73	.238	39.0	1.0	1.54	16.65	12.8	599.8	.990	600.0
7	600	360	-1.75	360	1360	15.6	.272	38.25	1.0	1.58	16.65	13.15	598.2	.954	627.0
8	617	380	-17.35	359	1365	14.35	.250	36.0	2.0	3.03	16.60	25.1	595.2	.831	608.0
9	608	497	-31.7	305	1380	11.5	.271	36.5	6.0	8.01	16.60	67.5	587.2	.729	805.0
10	805	649	-43.2	343	1420	8.65	.151	18.0	22.0	23.8	17.0	219.0	561.4	.615	908.0
11	908	825	-51.8	315	1550	6.8	.118	8.0	105.0	108.5	17.7	602	452.0	.522	867.0

MASS = 300 KG. INITIAL VELOCITY = 1200 MET. SEC.  $\theta_0 = 91^\circ$   $\Sigma \Delta t = 178$  SEC. APPROX.

The meaning of the symbols is as follows:

The number of the chord is denoted by  $r$ ; the velocity of the projectile is denoted by  $v$ ; and its  $x$ -component, by  $v_x$ . The inclination of the tangent at the beginning of the arc is  $\theta_r$ . The drop away from the tangent, due to gravity, which is of the second order of smallness with respect to the length of the arc, is denoted by  $\Delta y$ . The mean ordinate of a given element is indicated by  $y$ . The resistance  $R$  is found from the graphical table (Fig. 2). The change in the horizontal component of the velocity is  $\Delta v_x$ , the time taken for the projectile to traverse one arc is  $\Delta t$ .  $D_x$  represents the "set-back" computed from the resistance, representing the amount by which the projectile falls short of the assumed horizontal distance owing to the resistance of the air. The height reached at the end of the arc is

$$y = (x - D_x) \tan \theta - \Delta y.$$

The most important thing in a ballistic calculation is the knowledge of the ballistic, or resistance, function  $f(v)$ . We have here made use of the famous result of the greatest of recent ballisticians,

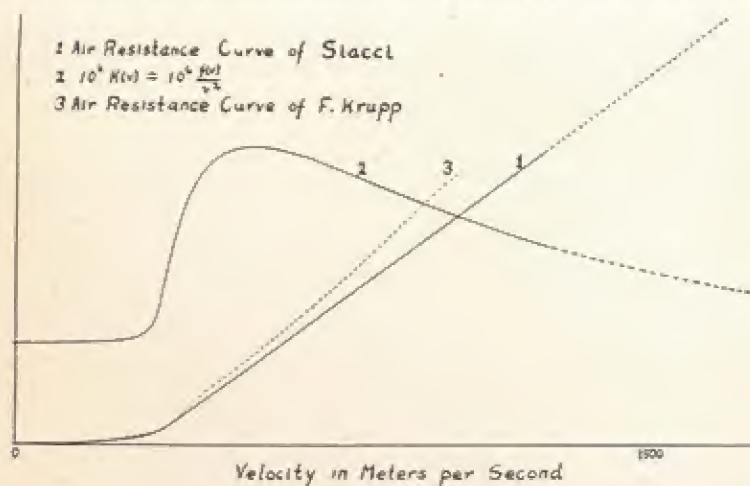


FIG. 1.

General Siacci, in his papers in the *Rivista di Artiglieria e Genio* (1896), from which it appears from the results of thousands of shots made by Bashforth in England, Mayevski in Russia (shots



made at Krupp's), Hojel in Holland, and Krupp in Germany, that for velocities of over 300 meters per second the law is represented with great exactness by a straight line. Although experimental results do not go above velocities of 1,200 meters/sec., I have felt no hesitation in extrapolating for such values as are here used. In Fig. 1 are shown, in Curve 1, the values given by Siacci. In Curve 2, the values of the function  $K(v)=f(v)/v^2$ , and in Curve 3 the values of  $K(v)$  as given by Krupp. It is only fair to say that the results of the French Commission de Gâvre more nearly resemble Curve 3 than Curve 1.

The use of the linear law (originally suggested by Chapel) has been recommended by the Comte de Sparre in a paper published in 1901.

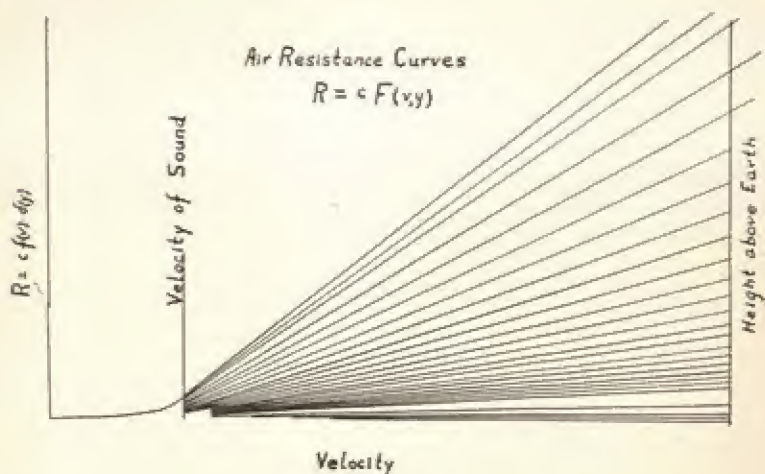


FIG. 2.

In order to expedite matters, a graphical chart was prepared (Fig. 2) with abscissas denoting the velocity in meters per second, containing straight lines and inclinations proportional to the densities of the air at different heights. On the right is a scale giving the height above the earth and by following the line corresponding the resistance  $R$  is read off on the scale at the left.

The equations used are as follows:

$$(7) \quad \Delta y = \frac{g}{2x_0'^2} (\Delta x)^2, \quad (8) \quad \Delta v_x = \frac{c_y}{g} v f(v) \Delta \theta,$$

$$(9) \quad \Delta t = \frac{\Delta x}{v_x'}, \quad (10) \quad \Delta \theta = -\frac{g \Delta x}{v_x'^2},$$

$$(11) \quad \frac{v_x' - \Delta v_x'}{\cos \theta_{r+1}} = v_{r+1}, \quad (12) \quad D_x = \frac{\Delta v \cdot \Delta t}{2}.$$

The calculation is made as follows: An arbitrary value of  $x$  is selected, the drop  $\Delta y$  is calculated from (7), the change in angle from (10), the "set-back" from (12), and, finally, the corrected value of  $y$  corresponding to the given  $x-D_x$  is obtained. One row of values is obtained for each element of the trajectory.

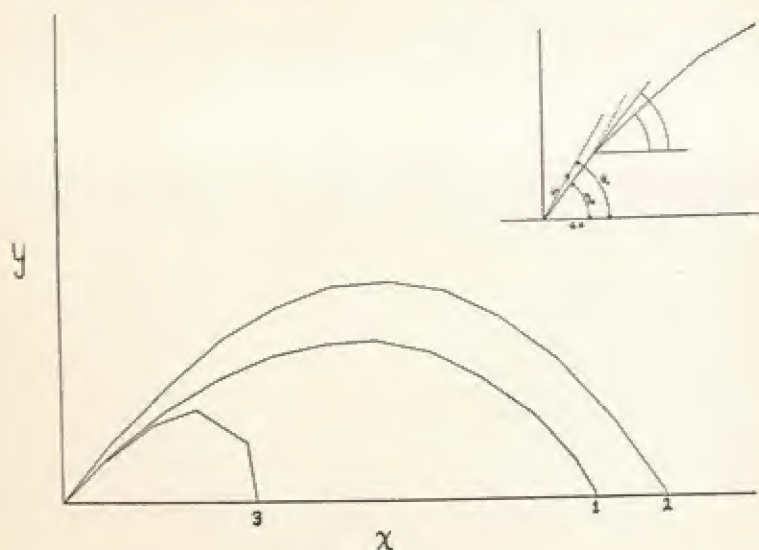


FIG. 3.

Fig. 3 shows the details of the graphical method. After the chords are drawn by means of a flexible ruler, the trajectory is drawn through the vertices of the polygon constructed.

In Fig. 4 are shown some of the most striking results. The heavy black curve shows the surface of the earth and the change of



range, amounting to about a mile, that it would cause (neglecting the conversions of the verticals).

The method of choosing was frankly one of guessing. At first, an angle of departure of  $45^\circ$  was assumed with an initial velocity of 1,300 meters/sec. This gave Curve 1. The angle of departure was then increased to  $52^\circ$ , which gave Curve 2, with a range of 120 kilometers. In order to show the enormous effect of the resistance

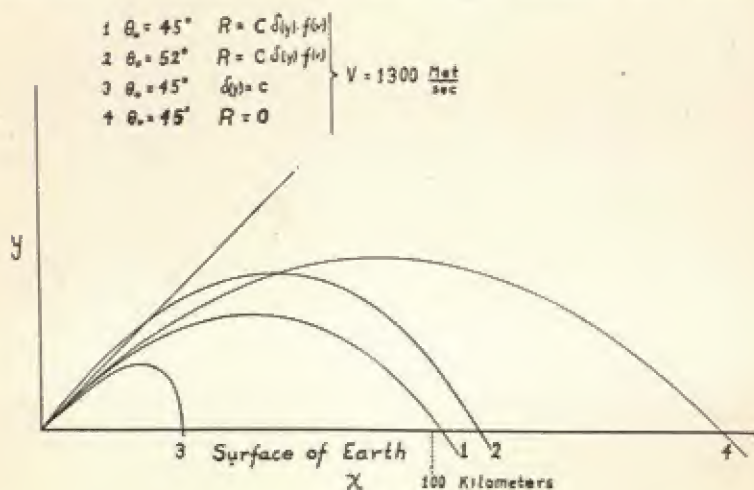


FIG. 4.

of the air, No. 4 is drawn showing the parabolic or vacuum trajectory, with a range of 174.4, and, finally, No. 3, on the assumption that the air has the constant density found at the surface of the earth. Further, the trajectory that we should have in case the density had the constant value, taken at a height two thirds of the maximum, as suggested by Colonel Ingalls for shots nearer the surface of the earth, was calculated. The range obtained was approximately 56 kilometers, quite different from the correct value of Curve 1.

*Note, May 2, 1919.*—The foregoing paper, which was read over a year ago, has, of course, lost the timeliness that it had at that moment. In fact, I have been advised by a high ballistic authority not to publish it, as such calculations are now "a matter of routine."

To this I have replied, that, although they may be *now*, they were not when I read the paper, and even now are not so in the Navy. In fact, when I inquired of a high naval authority how long it would take to calculate such a trajectory, he replied, "About two days." I said that we did it with two men in an hour.

Since then far better methods have been developed, but as I have seen only one publication of a trajectory, viz., by Major J. Maitland-Addison, R. A. (*Journal of the Royal Artillery*, Vol. XLV., No. 4), which confirms my results, I publish the paper as read, in the interest of the history of the matter, regretting that more pressing matters have so delayed the publication.



## ON A NEW (?) METHOD IN EXTERIOR BALLISTICS.<sup>1</sup>

BY A. G. WEBSTER AND MILDRED ALLEN.

(Read April 20, 1918. Received June 4, 1919.)

Whether the method to be described deserves to be called new or not is a matter of opinion, since the instrument here used was designed and built by one of us twenty-eight years ago, and has been described in an article in the *Physical Review*, Volume 6, May-June, 1898. The method of measuring time by means of the charging or discharging of a condenser has been used by Pouillet, and has been applied to ballistics by Cranz in Germany and Sabine in England, but so far as we know the electrometer has not been applied to ballistics.

The essential part of the instrument for measuring the time is shown in Fig. 1. A projectile drops from an electromagnet upon the two levers shown in the middle, the one on the right being carried on a carriage adjustable by means of a micrometer screw. By knowing the height through which the projectile falls, the velocity of the projectile on striking the lever is known.

The arrangement of the apparatus is shown in Fig. 2. The battery charges the condenser through a resistance, the condenser being short-circuited through conductor (*a, b*), which in the calibration is the left hand lever of the drop interrupter. When the circuit is broken the condenser begins to charge in accordance with the equation

$$q = q_0(1 - e^{-\frac{t}{RC}}).$$

A curve of calibration is shown in Fig. 3, by which it appears that times may be measured of the order of one-millionth of a second.

In the ballistic application (*a, b*) and (*c, d*) are two strips of tin foil stretched tightly between the brass supports. These are shot

<sup>1</sup> Contribution from the Ballistic Institute, Clark University, No. 3.

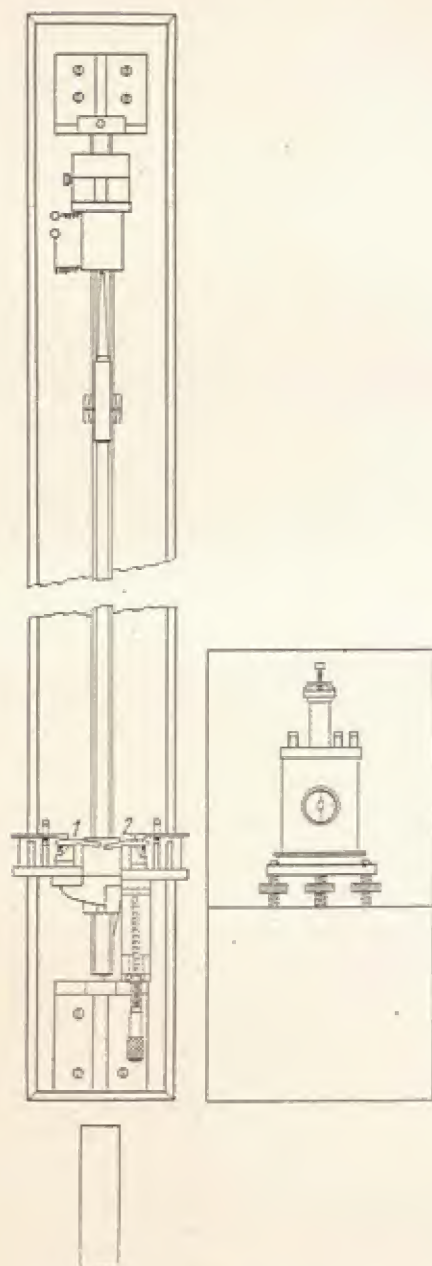
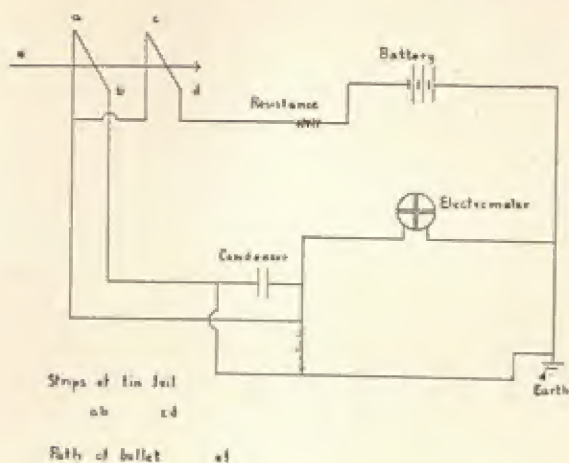


FIG. 1.



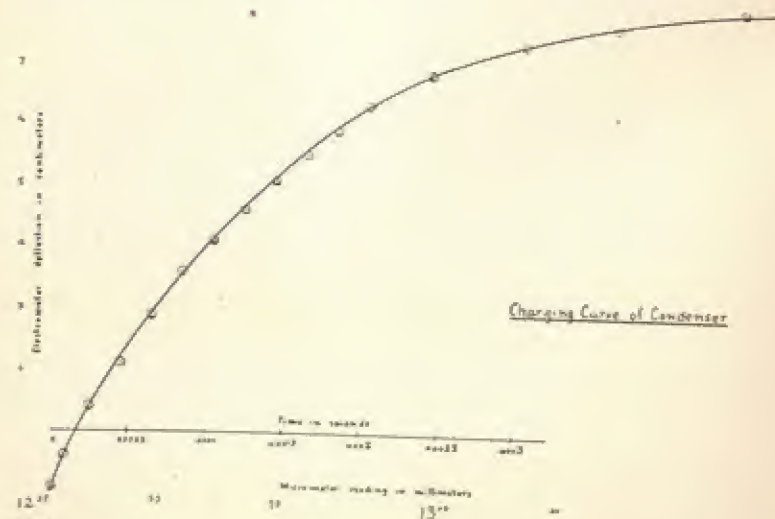


Arrangement of apparatus

M. Allen

FIG. 2.

Battery 3 dry cells  
Resistance See above



M. Allen

FIG. 3.

away by a bullet. It is possible to measure the velocity of a bullet when the strips of tin foil are an inch apart, but in general a distance of two or three feet is conveniently taken. This may be contrasted with the distance of one hundred or one hundred and fifty feet generally used in ballistic laboratories of arms companies.

The table of results is given both for a small saloon rifle and for a .44 calibre gun. It is not claimed that this method would be of great use in the open, but in a laboratory it is certainly a very great convenience.

Saloon Rifle.			.44 Calibre Rifle.
Deflection in Cms.	Time $\times 248$ in Sec.	Velocity in Cms./Sec.	Velocity in Ft./Sec.
5.2	.037	30,162	—
5.4	.039	28,615	1,303.0
5.3	.038	29,368	1,330.2
5.3	.038	29,368	1,329.2
5.3	.038	29,368	1,326.4
5.3	.038	29,368	1,284.0
5.3	.038	29,368	—
5.4	.039	28,615	1,375.7
5.4	.039	28,615	1,327.3
5.1	.036	31,000	1,326.4
5.5	.041	25,363	1,339.8
5.4	.039	28,615	1,320.7
Average velocity ( $v$ ) .....		28,985	1,337.98 av.



## CHARACTERS AND RESTORATION OF THE SAUROPOD GENUS CAMARASAURUS COPE.<sup>1</sup>

FROM TYPE MATERIAL IN THE COPE COLLECTION IN THE AMERICAN  
MUSEUM OF NATURAL HISTORY.

(PLATE I.)

BY HENRY FAIRFIELD OSBORN AND CHARLES CRAIG MOOK.

In 1902 the Cope Collection of Fossil Reptiles was presented to The American Museum of Natural History by President Morris K. Jesup. It included all of Cope's types and other dinosaur material of Morrison age from the vicinity of Canyon City, Colorado. Several of these types antedated in definition Marsh's types from beds of similar age. Cope's references were full but accompanied by few figures; Marsh's came later and were adequately illustrated. Marsh also issued in the publications of the United States Geological Survey two more or less complete summaries of the characters of these animals, which were fully illustrated and widely distributed. Consequently they became well established in the literature, while Cope's are still unrecognized and imperfectly known. Our object has been to describe and determine as fully as possible Cope's types, especially of the Sauropoda, the most important of which is that of *Camarasaurus*. This generic name antedates *Morosaurus* Marsh, with which it is considered congeneric, by about one year.

The fugitive descriptions and determinations by Cope, Osborn, Riggs and Mook may now be replaced by thorough descriptions and illustrations, in which the characters of the genus *Camarasaurus* are determined in great detail, so far as the nature of the material will permit. All the type material, including the types of six genera and eleven species, has been figured and these animals, practically unknown since their original mention forty years ago, have now been brought to light.

<sup>1</sup> Partly printed in the *Proceedings* of the Palæontological Society, *Bulletin* of the Geological Society of America.

## OCCURRENCE AND COLLECTING OF MATERIAL.

*Original Discovery and Collecting.*—In the spring of 1877 Mr. O. W. Lucas, superintendent of public schools in Canyon City, Colorado, discovered some large fossil bones, which he sent to Professor Edward D. Cope. The date of this discovery is not definitely known, but it appears to have been some time in March. From the first specimens which reached the Cope Museum in Philadelphia, Cope made his original description of *Camarasaurus* and founded the genus; this description was published August 23, 1877. The name *Camarasaurus*, or "chambered saurian," was given in reference to the cavernous nature of the centra of the cervical and dorsal vertebræ, in connection with the lateral cavities now known as pleurocoelia. After receiving the original bones, Cope employed collectors who gathered more material, all of which is now in the American Museum.

*Subsequent Collecting.*—The amount of material collected by Cope's parties was very large. It was not all prepared at once, but a considerable amount of it was cleaned up by Jacob Geismar under Professor Cope's direction. In 1877 a reconstruction of the skeleton of *Camarasaurus* was made by Dr. John A. Ryder, under the direction of Professor Cope. This reconstruction, the first ever made of a sauropod dinosaur, was natural size and embodied representations of the remains of a number of individuals; it was over fifty feet in length. It was exhibited at a meeting of The American Philosophical Society on December 21, 1877, and since has been exhibited a number of times at the American Museum (where it is now preserved) and elsewhere. A greatly reduced copy of it was published by Mook in 1914.<sup>2</sup>

After the collecting of the material which formed the basis of the above-mentioned reconstruction, Cope's collectors sent in more material. This collecting was continued until 1880.

*The Quarries.*—Unfortunately the quarry records of the Cope Canyon City material have been lost; no quarry diagrams are mentioned in any of Cope's descriptions, and it is unlikely that any were

<sup>2</sup> "Notes on *Camarasaurus* Cope," by Charles C. Mook, *Ann. New York Acad. Sci.*, Vol. XXIV., pp. 19-22, May 21, 1914, 1 fig.



made. Two large quarries are known to have existed and their location is known at the present time.

One large quarry is situated about 500 yards west to southwest of a small conical hill, locally known as the "Nipple," a considerable distance from the edge of the escarpment. This quarry is called Cope Quarry No. 1. Here the Morrison is capped by the Purgatoire sandstone and the quarry site is very definitely marked by a great excavation. The matrix is chiefly reddish to brownish, and *probably* most of the bones of a reddish color, collectively known as the red series, came from this quarry.

Another quarry is situated almost at the crest of the escarpment which forms the west boundary of Garden Park, and near the base of the "Nipple." It is not very definitely marked, but traces of the work of excavation by Cope's collectors and others mark its site. This quarry is called Cope Quarry No. 2. The matrix is largely grayish, and it is likely that it furnished most of the bones which are known collectively as the yellow series, although this is not certain. Some of the matrix is neither gray nor yellow, and it is possible that certain of the yellow bones may have come from the other quarry. The value, therefore, of the color of the matrix, in determining the field association of the bones, is limited. Variation in color depends upon the condition of the iron oxide of the matrix, and probably also upon the original conditions of decay of the animal tissue. The quarry was reworked by Mr. J. B. Hatcher for the Carnegie Museum in 1901.

There may have been one more quarry in this vicinity which perhaps furnished some of the sauropod material, but the nature and the location of it are not known; indeed, the types of *Amphicalias altus* and *A. latus* may have come from this quarry, about which no reliable information is available. All three quarries are located a short distance north of the quarry worked by Mr. M. P. Felch, later known as the Marsh-Hatcher quarry, which yielded the genotypes *Diplodocus longus* Marsh and *Haplocanthosaurus priscus* Hatcher, also *H. utterbacki* Hatcher. The Marsh-Hatcher quarry was excavated at a lower geological level than the Cope quarries.

## PREPARATION AND RESEARCH IN THE AMERICAN MUSEUM.

*Acquisition.*—The Cope Collection of Fossil Reptiles had been examined in Philadelphia by Dr. W. D. Matthew and was transferred to the American Museum under his direction. The preparation of the material was made by Messrs. Kaison, Charles and Otto Falkenbach, Lang, Christman, Hoover, Brückner, Carr and Horne.

*Research in 1904.*—Doctor Matthew went over the material, under the direction of Professor Osborn, and catalogued and identified it so far as was possible with the aid of the records available, distinguishing the material obtained in the earlier collecting in 1877 by Superintendent Lucas from that obtained in the later collecting in 1880 under Mr. Ira H. Lucas. The bones of the earlier collection were given the number 5760, with variations according to their identification as individuals, such as 5760' and 5760''; the bones of the later collection were given the number 5761, with a modification into 5761-*a* for a presumably different individual than the rest of 5761. Subsequently Professor Osborn and Professor W. K. Gregory made a further study of the vertebræ and arranged them provisionally into series, using in addition to the previous records the color of the bones, those of the red series apparently having come from a different quarry than those of the yellow series. Most, if not all, of the red bones probably came from Cope Quarry No. 1, and most, if not all, of the yellow from Cope Quarry No. 2.

In connection with this work, which was carried on in 1904, Mr. Rudolph Weber, then artist of the Department of Vertebrate Palæontology, made line drawings of many of the vertebræ. In 1906 some wash drawings of the skull material were made by Mr. Erwin S. Christman. These illustrations were originally prepared for the United States Geological Survey Monograph on the Sauropoda, in course of preparation by Professor Osborn. The cost of preparation of these drawings was borne by the Survey.

*Research in 1912-1919.*—In 1912 work on the Cope Sauropoda material was renewed as part of the preparation of the Sauropoda Monograph, which was being prepared for the Survey by Professor Osborn. This work was undertaken by the present junior author under the direction of the senior author. The entire Cope Collection



of Sauropoda from Canyon City was studied, among other material, with the object of separating the vertebræ and limb bones referable to *Camarasaurus*, *Amphicælias* and the other Cope genera, and arranging them in series *similar in size, proportion and color*, as well as determining the characters of *Camarasaurus* and *Amphicælias* and the less known genera. To a considerable extent this work consisted in verification of the previous work by Doctor Matthew and Professor Gregory, in modification of their results, in a few cases, and in adding to them to meet the present needs.

This research has terminated in the arrangement of the vertebræ and ribs in *morphological series*, which may represent originally distinct individuals, or may not. The attempt was made to associate the bones of single individuals so far as practicable, but in many cases evidence for this was insufficient and in such cases an attempt was made to assemble series that would be reasonably constituted in a morphological sense. The arrangement of the bones in these series is as accurate as it could be made, in view of the distorted, sometimes incomplete and badly mixed character of the material. The pairing of the girdle and limb bones was similarly undertaken, though no attempt was made to pair the ribs. In a few cases it has been possible to determine the relation of some of the girdle and limb bones with the vertebræ, but in most cases the original association is still unknown, though their possible association is very evident.

*Carnivorous Dinosaur Material and Types.*—The type of *Epanterias amplexus* consists of bones of a large theropod. There are some ribs among those of *Camarasaurus* which certainly do not agree in characters with the majority of *camarasaur* ribs, and do resemble those of the Theropoda. There is also a theropodous femur. They may be provisionally referred to this form. It is possible, if not probable, that the types of *Tichosteus lucasanus* and *T. æquifacies*, also of *Symphyrophus musculosus*, may be referable to the Theropoda. Cope's types of *Laelaps trihedrodon*, *Brachyrophus altarkansanus* and *Hypsirophus discurus* were also collected at this locality. The first of these is certainly a theropod; the position of the second and of the third is uncertain.

*Characters of the Genus Camarasaurus.*—The results of the investigations described above include determinations of the generic

characters of *Camarasaurus* and *Amphicalias*, so far as these characters are determinable from the material in the collection. The genus *Camarasaurus* is characterized by massive proportions. Throughout the skeleton, with the single exception of the ischium, the bones are stoutly constructed.

*Synonymy of Camarasaurus Cope and Morosaurus Marsh.*—In 1898 the synonymy of *Morosaurus* Marsh with *Camarasaurus* Cope was suggested by Osborn;<sup>3</sup> in 1902 this view was favored by Riggs;<sup>4</sup> in 1914 it was definitely adopted by Mook.<sup>5</sup> At present *Morosaurus* is considered to be a synonym of *Camarasaurus*, Cope's term having priority and therefore being valid.

*Characters of the Genus Amphicalias.*—*Amphicalias* is more slender than *Camarasaurus*; its remains resemble those of *Diplodocus*, but are somewhat larger than any known *Diplodocus*, and are somewhat more strongly constructed.

#### RESTORATION AND RECONSTRUCTION OF CAMARASAURUS.

*Ryder's Restorations.*—It would be hardly justice to the very able comparative anatomist, Dr. John A. Ryder, to publish, without explanation, his reconstruction (Fig. 1), roughly drawn, life size, and exhibited before The American Philosophical Society December 21, 1877.

The reconstruction was obviously made after one series of bones was exposed, but before Professor Cope had had time to give them much study. It would not appear that Professor Cope himself seriously studied the reconstruction, from the false arrangement of the teeth on the malar jugal arch, and from the placing of consolidated spines like those of the sacrum opposite the massive scapula. Twelve to thirteen vertebrae are consigned to the neck, close to the

<sup>3</sup> "Additional Characters of the Great Herbivorous Dinosaur *Camarasaurus*," Henry Fairfield Osborn, *Bull. Amer. Mus. Nat. Hist.*, Vol. X., Art. xii, June 4, 1898, pp. 219-233.

<sup>4</sup> "The Fore Leg and Pectoral Girdle of *Morosaurus*; with a Note on the Genus *Camarosaurus*," Elmer S. Riggs, *Field Col. Mus. Pub. 63, Geol. Ser.*, Vol. I., No. 10, pp. 275-281, Pls. XL., XLI., XLII., October, 1901.

<sup>5</sup> "Notes on *Camarasaurus* Cope," Charles C. Mook, *Ann. New York Acad. Sci.*, Vol. XXIV., pp. 19-22, May 21, 1914, 1 fig.





FIG. 1. First reconstruction of the skeleton of *Camarotaurus* Cope. This reconstruction was made in 1877 by Dr. John A. Ryder under the direction of Professor E. D. Cope. The original drawing was natural size; it was first exhibited at a meeting of The American Philosophical Society in Philadelphia, Pennsylvania, on December 31, 1877; since that time it has been exhibited at The American Museum of Natural History and elsewhere. It is still preserved in The American Museum as an historic document of great interest. The photograph is about one one-hundredth natural size.

true number. Eighteen vertebræ are consigned to the back, eight too many. Fifty-seven vertebræ are consigned to the tail, not far from the correct number. A complete set of claws is consigned to both the fore and the hind feet.

#### STILL UNKNOWN PARTS OF CAMARASAURUS.

1. In the accompanying restorations and reconstructions of *Camarasaurus* it is observed that our knowledge of this animal is still very incomplete regarding the structure of the pes, the foot bones being based on our knowledge of the pes of *Apatosaurus* or *Brontosaurus*.

2. It is also unknown or uncertain whether these animals possessed a set of abdominal ribs. One rib has been found which may possibly represent a member of the abdominal rib series.



FIG. 2. Restoration of the external appearance of *Camarasaurus*. Photograph of a model of *Camarasaurus* made under the direction of Prof. W. K. Gregory by Mr. E. S. Christman with the coöperation of the authors. This model is the result of very careful comparison of the *Camarasaurus* skeleton with previous sauropod models and with various living reptiles; it embodies extensive myological studies by Professor Gregory, and a thorough analysis of the characters of the skeleton.

3. The vertebral formula is still uncertain, although it is probable that the number was as follows: cervicals 13; rib-bearing dorsals 10, dorsosacral 1; consolidated primary sacrals 3; caudosacral 1; caudals 53.



## PRESENT RECONSTRUCTIONS AND RESTORATIONS.

The accompanying illustrations represent both a *reconstruction* and a *restoration*, based upon the topotype materials of four or more individuals of *Camarasaurus*. The skull characters are partly based upon the *Camarasaurus* topotype skull bones and largely upon the nearly complete skull originally referred to *Morosaurus* by Osborn; it is probable but not certain that this reference is correct.

It is very important to note that the four chief skeletons and two of the remaining skeletons are of approximately the *same linear measurements*, but differ slightly in proportions.

## CHIEF PROPORTIONS OF THE SKELETON.

1. The *enlargement and elevation of the shoulder* above the relatively depressed and reduced sacropelvic region is one of the most surprising features of this reconstruction. This proportion cannot be considered as actually *demonstrated*, because only two complete ilia were found with the four skeletons, and they belong to the same individual. It is possible that these ilia and other bones of the pelvis represent another individual than those individuals represented by the massive scapulocoracoid bones. The other pubes and ischia are of the same size as in the pelvis figured in the restoration.

This makes the highest point in the backbone between the shoulders, as contrasted with the previous restorations of *Brontosaurus* and *Diplodocus* by Osborn, in which the pelvic region is made the high point. Recent studies of *Apatosaurus* by Osborn and Gregory make the shoulders higher than the sacrum.

2. The neck is rather massive and the neck and shoulders bore the chief weight. The heaviest portion of the chest was at the fourth rib, where the relatively immobile hyposphen-hypantrum articulation of the dorsal vertebræ begins.

3. As shown in the articulated skeleton (Fig. 3) the total length and height of the animal, with the spinal curvatures and in the walking pose, were as follows:

Elevation of the head above the ground .....	20 to 22 feet
Total length from the front of the head to the tip of the tail ..	50 to 52 feet
Height of the backbone at the shoulder .....	13 to 14 feet

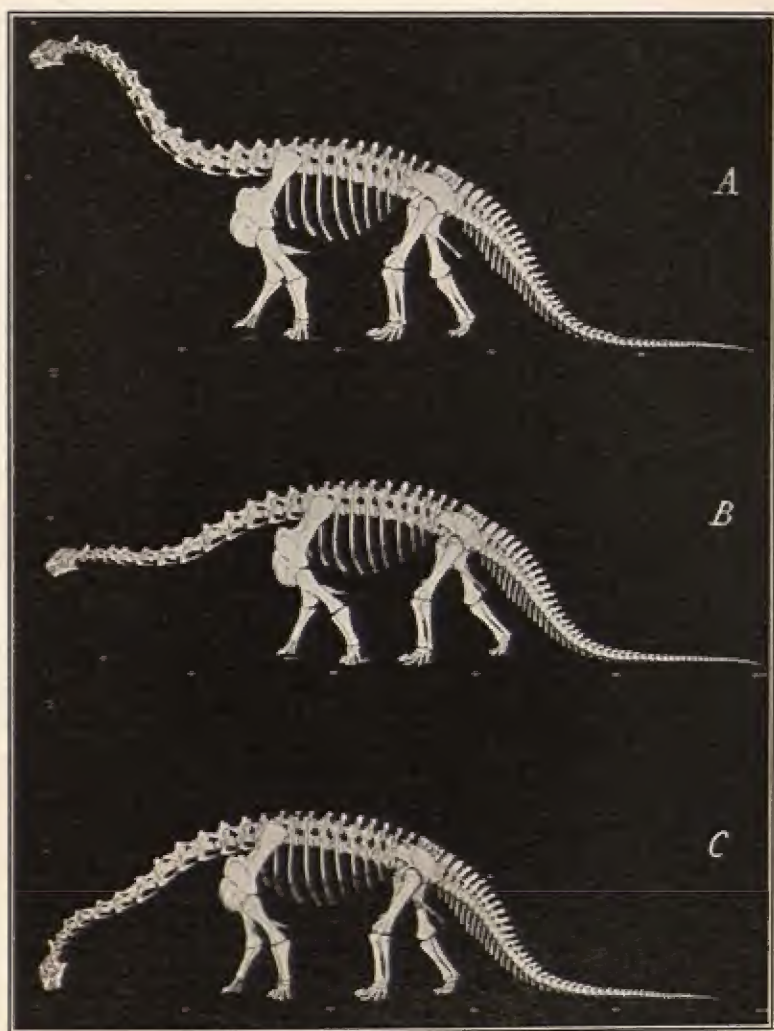


FIG. 3. Three poses of *Camarasaurus*. *A*, walking pose, head elevated. *B*, walking pose, head and neck horizontal. *C*, ground-feeding pose, head depressed. These photographs are made from drawings in which every bone is figured separately to a one-fifth scale and fastened upon a black background. This articulated drawing is successively placed in three poses, *A*, *B* and *C*, each photographed in turn. In the restoration and reconstruction the structure and arrangement of the phalanges of the feet are purely conjectural. The head of the animal attains a height of 20 feet (*A*). The maximum length in the extended position (*B*) is 52 feet. Length of backbone, without curvature, between 54 and 55 feet.



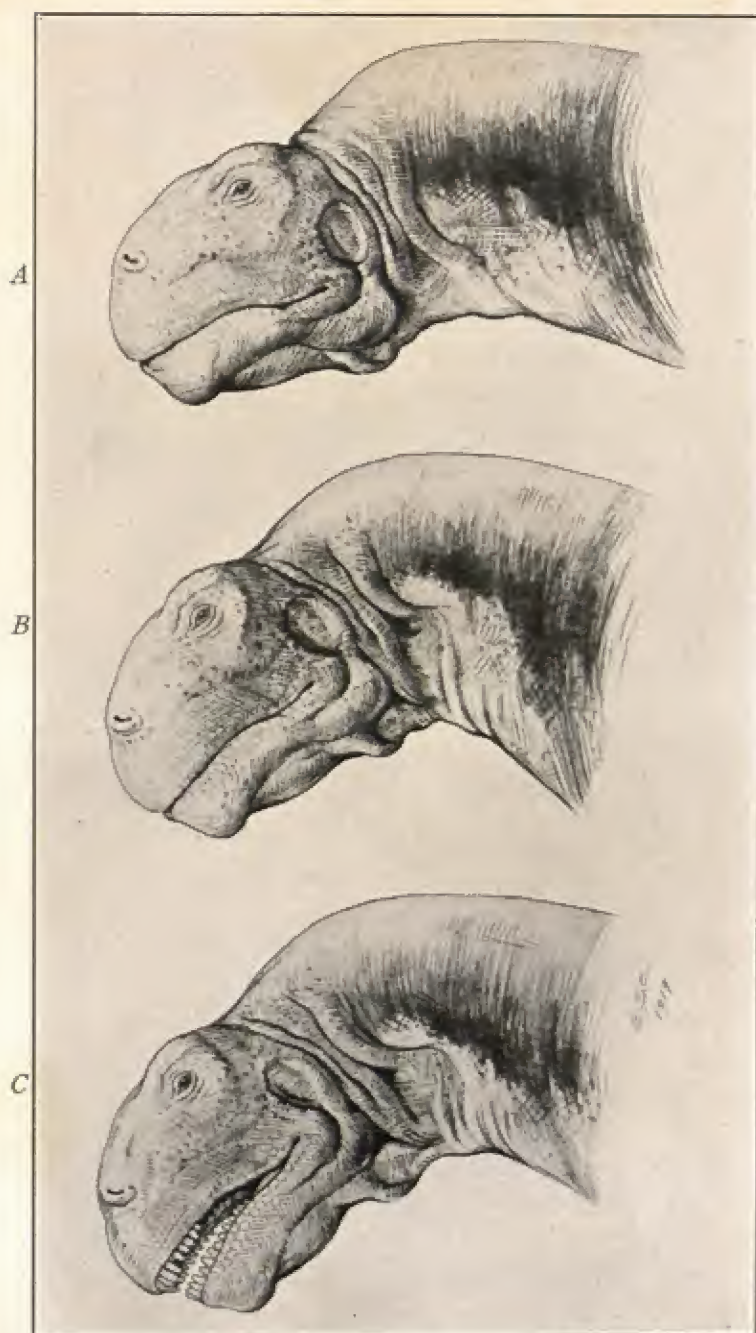
4. The head of the Sauropoda, as pointed out by Dr. W. J. Holland, has been mistakenly represented as parallel with the long axis of the neck, whereas it should be *flexed* or at an angle with the neck. In this respect our restoration gives a somewhat misleading impression, as the head should be bent down as in Pl. I, *B*, *C*.

#### COMPARISON WITH OTHER SAUROPODA.

As compared with the two other Sauropoda, in which the skeleton is now fully known, namely, *Diplodocus* and *Apatosaurus*, *Camarasaurus* is relatively the most massive, the most elevated at the shoulder, the most elongated over all, and the most ponderous in its proportions. It was apparently not provided with the whip-like terminal tail vertebræ so characteristic of *Apatosaurus* and *Diplodocus*; the vertebræ steadily lessen in longitudinal diameter and would indicate that the tail came to a rather abrupt point.

#### EXTERNAL APPEARANCE OF CAMARASAURUS.

The external appearance of the head is shown in Pl. I. The head is extremely short and deep in its proportions, contrasting with the elongate head of *Diplodocus*. The animal as a whole is sketched in Fig. 2. This represents an animal terrestrial in gait but adapted to an amphibious life, with smooth rounded limbs.



Three studies of head of *Camarasaurus*. *A*, head extended and bent upwards. *B*, neck flexed and head bent downwards. *C*, neck flexed and head bent strongly downwards to show ground-feeding pose and to expose the teeth. The head of *Camarasaurus* is extremely short and deep. The nostrils and eyes are elevated. The tympanum leaves a space behind the quadrates.





TROGLOGLANIS<sup>1</sup> PATTERSONI A NEW BLIND FISH  
FROM SAN ANTONIO, TEXAS.<sup>2</sup>

By CARL H. EIGENMANN.

(Read October 3, 1919.)

Professor J. T. Patterson, of the University of Texas, has secured a specimen of a small blind catfish from an artesian well in San Antonio, Texas, belonging to Mr. George W. Brackenridge. Pending the securing of other material the following facts may be of interest.

The specimen is without pigment. There is no external evidence of any vestige of an eye. It has a total length of 85 mm. Other and larger specimens were emitted but not preserved.

The occurrence of blind fishes in Texas was predicable. There are large springs, the outlets of underground rivers in the same region and artesian wells tap the subterranean waters in various places about San Marcos and San Antonio. The flow of the artesian well of the Bureau of Fisheries at San Marcos shows that the underground waters have an abundant cave fauna. From this well and some neighboring caves I secured twenty (20) species of invertebrates and the blind salamander *Typhlomolge* in less than a week's stay. The surprise therefore is not that cave fishes have been secured from the underground rivers, but that they have not been found before. It is more of a surprise that the fish should be a catfish rather than a member of the blind-fish family of *Amblyopsidae*, found in Tennessee, Arkansas and northward.

However, the occurrence of blind catfishes somewhere in the Mississippi basin was also predicable. Some of the catfishes are nocturnal in habit and live in crevices, under rocks, stumps and such, and detect their food by means of touch and taste organs scattered

<sup>1</sup> τρωγλη, ῥ = cave; γλαριε, ῥ = catfish, originally from Glanis, the name of a river.

<sup>2</sup> Contribution from the Zoological Laboratory of Indiana University, No. 167.



over their entire body and especially over their barbels. All of these facts predispose toward a cave existence, and various catfishes have become blind in different parts of the world. I have found normal-eyed catfishes in the caves of both Indiana and Kentucky. Cope secured blind catfishes, dark in color, *Gronias nigrilabris* from eastern Pennsylvania. I have recently called attention to *Typhlobagrus kronei* Ribeiro<sup>3</sup> from the Cavernas das Areiras, Iporanga, Sao Paulo, Brazil and more recently to *Phreatobius cisternarum* Goeldi,<sup>4</sup> the blind catfish living on the Island of Marajo. These belong to the Pimelodinae, a subfamily of catfishes not found in North America.



FIG. 1. *Trogloglanis Pattersoni* Eigenmann. Type.

*Gronias nigrilabris*, from eastern Pennsylvania, is without question a derivative of the universally distributed *Ameiurus* of the eastern and central United States. *Typhlobagrus*, from southeastern Brazil, is derived from *Pimelodella*, a genus widely distributed in South America, a member of the Pimelodinae. *Phreatobius* is more remotely related to *Heptapterus*, another but very different member of the Pimelodinae.

The new Texan blind fish, judging by the position of its dorsal and ventral fins, as well as by its adipose fin, is derived from a fish-like *Schilbeodes*, a genus of catfishes with nearly a dozen species, generally distributed from the St. Lawrence to Texas. *Schilbeodes*

<sup>3</sup> *Memoirs Carnegie Museum*, VII., p. 255. Plate XXXIV., April, 1917.

<sup>4</sup> *L. c.*, p. 372, Plate LVI., 1918.

*nocturnus* has been found in the springs (mouth of the underground river) at San Marcos and at various other places in Texas and is the only species of the genus recorded from Texas. *Schilbeodes nocturnus* is, however, not closely related to the blind catfish living in the underground rivers of the same region.

I have called attention to the fact that the species living in the caves of the south are more intimately adapted to their subterranean home than those of the north. The eyes of the Texan *Typhlomolge* are more degenerate than those of the salamanders of Missouri. Judging from external appearance the eyes of the Texan *Trogloglanis* are more degenerate than those of any of the blind fishes from farther north. The technical description of *Trogloglanis* follows:



FIG. 2. Outlines of the head as seen from above.

Head similar to that of a tadpole, as broad as long; mouth inferior; teeth?; adipose fin long and low, rounded posteriorly, connected at its base with the accessory caudal rays; no external evidence of eyes; distance between origin of dorsal and tip of snout half as great as origin of dorsal from the end of the adipose; distance between snout and origin of ventrals  $1\frac{1}{4}$  in the distance between origin of ventrals and base of middle caudal rays; pectoral spine strong and pointed, about two thirds as long as the longest ray, about equal to the length of the head behind the posterior nares, smooth in



front, its posterior margin with seven straight teeth, less than half the width of the spine; caudal truncate, with numerous accessory rays; dorsal spine equal to the pectoral spine; base of adipose fin equal to the predorsal area; anal but slightly rounded, its highest ray equal to the length of the head. Nasal barbel reaching very nearly to end of opercle, maxillary barbel to the pectoral spine, mental barbels a little beyond the edge of the gill-opening.

Head 4.4 in the length; depth 6; D. I. 7; A. 14; P. I. 9; V. 8.

The specimen was collected by Mr. G. W. Brackenridge of San Antonio, Texas. Mr. Brackenridge gave the specimen to Professor Patterson who sent it to the author for determination. It is catalogued as No. 15240 Indiana University Museum.

## POLARIZED LIGHT IN THE STUDY OF ORES AND METALS.<sup>1</sup>

By FRED. E. WRIGHT.

(Read April 14, 1917.)

The measurement of the optical properties of transparent minerals, even in minute, irregular grains, is a simple task with modern petrographic microscope methods and is accomplished by petrologists as part of ordinary routine work. But the determination of the optical constants of opaque substances is difficult and is rarely attempted by microscopists; all observations are necessarily made in reflected light and are restricted commonly to the determination of color, of the character of crystallization, and of the behavior of the mineral or metal plate toward reagents and abrasives. It is generally recognized that if methods were available by means of which the optical constants of opaque substances in fine particles could be readily ascertained these methods would be of great value not only to students of ores and opaque minerals, but especially to metal-

<sup>1</sup> The manuscript of this paper was finished in March, 1917, and is here presented without alteration. A brief resumé of the results of the investigation was given at the meeting of the American Philosophical Society in April, 1917. With our entrance into the war the writer joined the Army, and the publication of this paper was accordingly postponed.

In the theoretical section of this paper certain standard equations are derived and expressed in Cartesian coördinates. The expressions would have been much simpler and shorter had the methods of vector analysis been employed; but this was not done and the equations are developed in the usual notation in order that they may be easily accessible to the reader interested in this particular subject. Many of the problems of crystal optics are, however, essentially vectorial in character and yield most readily, as do many problems in electricity (alternating currents, wireless telegraphy), to treatment by vector analysis. In vector analysis the imaginary quantity  $i = \sqrt{-1}$  is treated simply as an operator rotating a vector through 90°. This greatly simplifies the interpretation of equations containing complex quantities. An interpretation of this kind of many of the equations in the present paper would undoubtedly render them more intelligible, but this would have greatly increased the length of the paper and was accordingly not attempted.



lographers in the study of metal alloys. Unfortunately the explanation of the phenomena presented by opaque bodies is somewhat involved and the experimental measurement of the optical constants of such substances is encumbered with difficulties which, in many cases, allow only approximate results to be obtained at best. In view of these facts it has seemed to the writer that a useful purpose may be served by a critical discussion, based on the commonly accepted version of the electromagnetic theory of light for absorbing bodies, not only of the phenomena which might be of value for diagnostic purposes, but also of the factors underlying the several methods, old and new, which may be applied to the measurement of the few determinable optical properties of opaque bodies. A proper appreciation of the possibilities and also of the limitations of the application of polarized light to the study of opaque substances can only be had by a proper understanding of the fundamental principles involved and of their relative significance in practical diagnosis.

In the theoretical treatment of the general problem emphasis will be placed on the phenomena resulting on perpendicular reflection (angle of incidence = 0), because most metallographic observations with the microscope are made under conditions of vertical illumination. The attempt will be made to present the fundamentals of the subject and to indicate the mode of derivation of the equations required. Although several new relations are given, the treatment as a whole is necessarily along lines which have been followed by others. In the preparation of the section on theory the following books and articles have been specially consulted: P. Drude in Winkelmann's "Handbuch der Physik," Vol. VI, and in *Annalen der Physik*; "Lehrbuch der Optik," by P. Drude; "Lehrbuch der Kristallphysik," by F. Pockels; "Physical Optics," by A. Schuster; "The Analytical Theory of Light," by J. Walker; and "Physical Optics," by R. W. Wood.

The results of the investigation may be summarized by stating that in general the optical constants, such as refractive indices and absorption indices, cannot be satisfactorily ascertained on small polished random sections; that the application of polarized light enables the observer ordinarily to determine whether the crystal plate is isotropic or anisotropic and also to ascertain the degree of aniso-

tropism; that for this determination methods based either on the contrast in intensity of the two reflected components or on the amount of rotation of the plane of polarization on reflection of the incident plane-polarized light may be employed; that methods based on the phase difference between the two reflected components are in general of little value because of the small differences in phase which ordinarily result for a relatively large change in birefringence or biabsorption.

Several new methods are described for detecting anisotropism in opaque substances; of these, that requiring the use of the bi-quartz-wedge-plate is the simplest and has been found in practice to be superior to any heretofore suggested.

#### THEORETICAL.

Light waves on passing through homogeneous material are absorbed to a greater or less degree. In transparent media the amount of absorption (in the visible spectrum) is relatively slight and can be neglected for most purposes; but in absorbing media there is an appreciable weakening in intensity even in thin plates, which gives rise to the phenomena of absorption. No body is, however, perfectly opaque (perfect absorber) or perfectly transparent, and the terms transparent and absorbing are relative terms which express, in a general way, the degree of absorption in the visible spectrum. The conditions may, of course, be reversed in the infra-red or ultra-violet. The experimental law of absorption, as expressed by Lambert, states that in a homogeneous medium each layer of equal thickness absorbs an equal fraction of the light transmitted; if the layers be considered to be one molecule deep, as in some crystals, then each layer absorbs the same percentage of the light which passes through it. In other words, for a layer of given thickness the intensity of light transmitted (total light less absorbed light) is proportional to the intensity of the incident light or

$$\frac{dI}{dl} = -I. \quad I = I_0 e^{-ml}, \quad (1)$$

where  $I_0$  = intensity of incident light,  $I$ , intensity of transmitted light,  $l$ , thickness of layer, and  $m$ , the absorption modulus (i.e., the



density of a layer of unit thickness<sup>2</sup>) ; since the intensity varies with the square of the amplitude of vibration of the transmitted light, the equation is valid

$$A = A_0 e^{-\frac{2\pi}{\lambda_0} \cdot k \cdot l} = A_0 e^{-\frac{2\pi}{\lambda} \cdot \kappa \cdot l}, \quad (2)$$

in which  $A_0$  is the amplitude in *vacuo*,  $A$ , amplitude in the medium after passage through thickness  $l$ ,  $\lambda$ , wave-length in material,  $\lambda_0$ , wave-length in *vacuo*,  $k$ , the absorption coefficient,  $\kappa$ , the absorption index. But

$$\frac{A^2}{A_0^2} = \frac{I}{I_0} = e^{-\frac{4\pi}{\lambda} \cdot \kappa \cdot l} = e^{-\frac{4\pi}{\lambda_0} \cdot k \cdot l} = e^{-ml}; \quad (2a)$$

therefore

$$k = n\kappa \quad \text{and} \quad m = \frac{4\pi k}{\lambda_0} = \frac{4\pi \kappa}{\lambda}.$$

The significance of the absorption index can best be realized by a transformation of equation (2a)

$$\ln \frac{I_0}{I} = \frac{4\pi}{\lambda_0} l \cdot n \cdot \kappa$$

or expressed in ordinary logarithms

$$\log_{10} \frac{I_0}{I} = \frac{4\pi \cdot 0.43429}{\lambda_0} \cdot l \cdot n \cdot \kappa.$$

<sup>2</sup> The significance of these terms is clearly expressed in photography in which the relative densities of the photographic plate serve to record more or less accurately the relative intensities of the light impinging upon it. The incident light produces changes of such nature in the silver bromide particles in the emulsion that after development the exposed particles remain as opaque specks of silver. The more intense the incident light, the greater the number of affected silver particles. In the developed plate the more silver specks there are per given area, the more light is stopped, and the more opaque and dense is the plate. Density is measured in number of silver particles per unit area (total weight of silver particles per unit area). If a layer is of such density that it transmits the fraction  $a$  of the incident light, then two such layers superimposed transmit  $a \cdot a$  or  $a^2$  of the light, three layers  $a \cdot a \cdot a$  or  $a^3$ ; thus the density increases in arithmetical, but the transmission decreases in geometrical progression. If  $I/I_0$  = percentage of light transmitted ( $= e^{-lm}$  equation (1)) the reciprocal,  $I_0/I$  is the opacity  $O = e^{ml}$  and the density  $D = \log$  opacity or  $ml$  or simply  $m$  for  $l = 1$ . A plate is said to have unit density  $D = 1 = \log$  opacity  $= \log I_0/I = \log 10$ , i.e., when it transmits only  $1/10$  of the incident light. Similarly a crystal plate of absorption-modulus 1 and of unit thickness transmits only  $1/10$  of the incident monochromatic light.

For a wave length  $\lambda_0 = .0005458$  mm. (near the mercury green line) this expression reduces to

$$\log_{10} \frac{I_0}{I} = 10000 \cdot l \cdot n \cdot \kappa. \quad (2b)$$

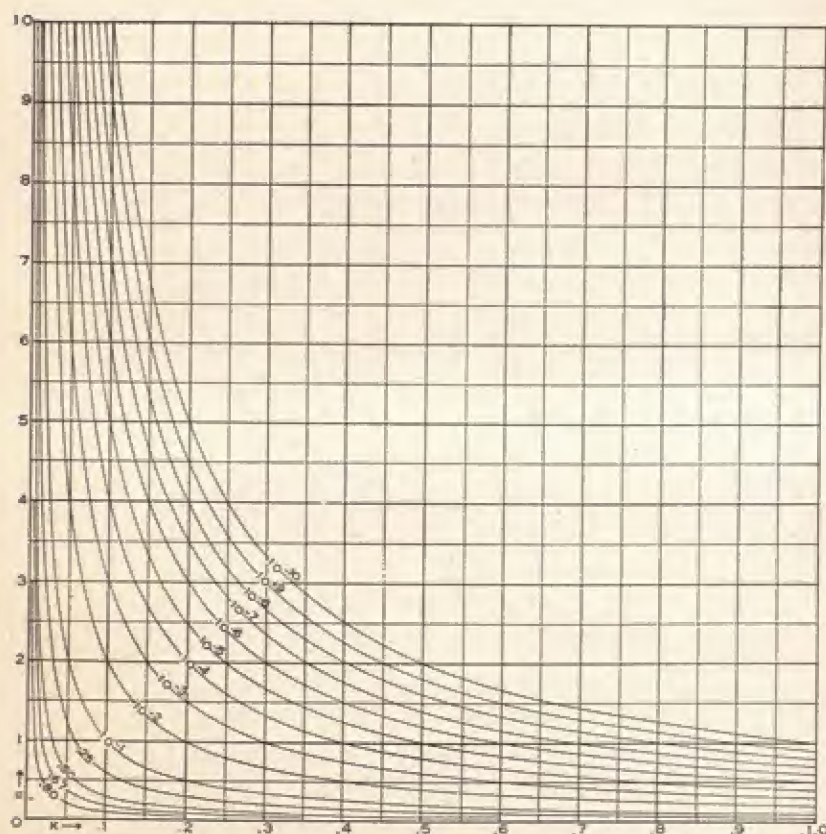


FIG. 1. In this figure the curves are equi-intensity curves indicating the ratio of the intensity of the transmitted light to that of the (normally) incident light for a plate 0.001 mm. thick, for greenish yellow light ( $\lambda_0 = 0.0005458$  mm.), and for different refractive indices (ordinates) and absorption indices (abscissæ). The pronounced effect of even a small absorption index in cutting down the transmission is evident from the curves.

A series of values computed by means of this equation on the basis of thickness  $l = 0.001$  mm. (1 micron about  $\frac{1}{20}$  the thickness of an ordinary rock thin-section) are listed in Table I. and represented



graphically in Fig. 1. From these the pronounced effect of  $\kappa$  in cutting out and absorbing the transmitted light energy is clearly evident. For any given thickness  $l$ , refractive index  $n$ , and absorption index  $\kappa$ , the amount of light absorbed can be obtained directly. From Fig. 1 it is evident that for a plate only 1 micron thick and for  $\kappa > 0.5$  the amount of transmitted light is almost negligible and the plate is practically opaque. The effect of using a plate  $\frac{1}{10}$  as thick is the same as that produced by a plate of the original thickness but with an absorption index  $\frac{1}{10}$  as large. Thus a plate of refractive index  $n=2$ , thickness  $l=0.001$  mm. and absorption index  $\kappa=0.5$  transmits  $10^{-10}$  of the incident light while a plate of the same refractive and absorption indices but  $\frac{1}{10}$  as thick (0.0001 mm.) transmits  $10^{-1}$  of the incident light. If we assume an intensity of illumination of 1,000 meter-candles and a threshold limit of vision 0.001 meter-candles, then  $10^{-6}$  is the least amount of light which can be detected; under these conditions for an ordinary rock section of thickness 0.02 mm., equation (2b) reduces to  $n\kappa=0.03$ ; therefore a mineral in a thin rock section whose absorption index  $\kappa$  exceeds 0.02, will appear perfectly opaque. The influence of even a very small absorption index is therefore exceedingly great in absorbing light energy.

TABLE 1.

In this table are listed the absorption indices  $\kappa$  of absorbing crystal plates of thickness  $l=0.001$  mm. and refractive index  $n$  which transmit given quantities  $I/I_0$  of the incident light. Thus a plate of this thickness, of refractive index  $n=2.0$  and absorption index  $\kappa=0.030$  transmits 0.25 of the incident light.

$I/I_0$	0.8	0.67	0.50	0.25	$10^{-1}$	$10^{-2}$	$10^{-3}$	$10^{-4}$	$10^{-5}$	$10^{-6}$	$10^{-7}$	$10^{-8}$	$10^{-9}$	$10^{-10}$
$n$														
1.0	.010	.018	.030	.060	.100	.200	.300	.400	.500	.600	.700	.800	.900	1.000
2.0	.005	.009	.015	.030	.050	.100	.150	.200	.250	.300	.350	.400	.450	.500
3.0	.003	.006	.010	.020	.033	.067	.100	.133	.167	.200	.233	.267	.300	.333
4.0	.002	.004	.008	.015	.025	.050	.075	.100	.125	.150	.175	.200	.225	.250
5.0	.002	.004	.006	.012	.020	.040	.060	.080	.100	.120	.140	.160	.180	.200
7.5	.001	.002	.004	.008	.013	.027	.040	.053	.067	.080	.093	.107	.120	.133
10.0	.001	.002	.003	.006	.010	.020	.030	.040	.050	.060	.070	.080	.090	.100

The characteristic feature of waves traversing an absorbing medium is the decrease in their vibration amplitude with distance of penetration; the waves are damped; the result is that for obliquely incident waves the vibration amplitudes along each wave front are not constant. In other words, the

surfaces of equal phase do not coincide with the surfaces of equal amplitude as in transparent media. In the electromagnetic theory transparent media are grouped under dielectrics (electric non-conductors) and in these Maxwell showed the possibility of the development of an electric current under the influence of an electric force, the current being proportional to the rate of change of the electric force; the current results on the shift in the density of the lines of electric force and varies in intensity with the rate of their displacement. If  $E$  is the electric force, the "displacement" current is proportional to  $\partial E/\partial t$  and is in fact equal to  $\epsilon \cdot \partial E/4\pi \cdot \partial t$  where  $\epsilon$  is the dielectric constant. A current is surrounded by a magnetic field such that the lines of magnetic force are closed curves. Maxwell showed that the work done in carrying an isolated magnetic pole around one of these curves is equal to  $4\pi$  times the electric current measured in electromagnetic units. Similarly a magnetic current or flux varies when the strength of the magnetic field changes and the lines of flow are surrounded by an electric field such that the lines of electric force are closed curves; the line integral of the electric force around one of these curves is numerically equal to  $4\pi$  times the magnetic flux; furthermore the magnetic flux is proportional to the rate of change of the magnetic force or  $\partial M/\partial t$  and is in fact equal to  $\mu \cdot \partial M/4\pi \cdot \partial t$ , in which  $\mu$  is the magnetic permeability. For vibrations of the high frequency of light waves  $\mu$  is practically equal to unity. From these relations Maxwell deduced the following differential equations:

$$\frac{\epsilon}{c} \frac{\partial X}{\partial t} = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}, \quad \frac{\epsilon}{c} \frac{\partial Y}{\partial t} = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}, \quad \frac{\epsilon}{c} \frac{\partial Z}{\partial t} = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad (3a)$$

$$\frac{1}{c} \frac{\partial u}{\partial t} = \frac{\partial Y}{\partial z} - \frac{\partial Z}{\partial y}, \quad \frac{1}{c} \frac{\partial v}{\partial t} = \frac{\partial Z}{\partial x} - \frac{\partial X}{\partial z}, \quad \frac{1}{c} \frac{\partial w}{\partial t} = \frac{\partial X}{\partial y} - \frac{\partial Y}{\partial x}, \quad (3b)$$

in which  $X, Y, Z$  and  $u, v, w$  are components of the electric and magnetic forces respectively and  $c$  is the ratio of the electrostatic to the electromagnetic systems of units and is numerically equal to the velocity of light.

To account for the phenomena observed in absorbing media the above equations are modified according to one of two possible hypotheses both of which involve the movements of electrons; the movements thus set up (translation in conductors, vibration in selective absorbers) absorb or divert part of the electromagnetic energy and convert it into heat (ohmic heating) and reduce the amount of energy available for the light vibrations. In electric conductors an electric force sets in motion streams of negatively charged electrons which are in effect the conduction current. The reaction is directly proportional to the impelling electric force,  $E$ , or to  $\sigma \cdot E$  in which  $\sigma$  is the absolute conductivity in electrostatic units (Ohm's law). A medium which is not a perfect insulator exhibits properties intermediate between those of a dielectric and of a conductor and the current consists of two parts: a displacement current and a conduction current. The expression for the current which covers both cases is then

$$\frac{\epsilon}{4\pi} \cdot \frac{\partial E}{\partial t} + \sigma \cdot E. \quad (4)$$



In light-waves the disturbance is periodic in effect and the time occurs only in the form of a factor the most general expression for which is  $\bar{A}e^{i\frac{2\pi}{T}t}$ ; in this factor  $T$  is the period of vibration and  $\bar{A}$ , which may be real, imaginary, or complex, is the amplitude vector. Under these conditions the expression (4) for the current may be written

$$\frac{1}{4\pi}(\epsilon - 2T\sigma i)\frac{\partial E}{\partial t}.$$

The only difference between this expression for the current and that for dielectrics is the replacement of the dielectric constant  $\epsilon$  by the complex quantity  $(\epsilon - 2T\sigma i)$ , in which  $i = \sqrt{-1}$ .

In crystals the dielectric constant and the conductivity are different in different directions. Experience has shown that the components of the electric displacement for any direction of wave propagation are homogeneous, linear functions of the field components. Thus the  $X, Y, Z$  components of the conduction current are

$$\sigma_{11}X + \sigma_{12}Y + \sigma_{13}Z,$$

$$\sigma_{21}X + \sigma_{22}Y + \sigma_{23}Z,$$

$$\sigma_{31}X + \sigma_{32}Y + \sigma_{33}Z,$$

those of the displacement current

$$\frac{1}{4\pi}\left(\epsilon_{11}\frac{\partial X}{\partial t} + \epsilon_{12}\frac{\partial Y}{\partial t} + \epsilon_{13}\frac{\partial Z}{\partial t}\right), \text{ etc.,}$$

wherein  $\sigma_{hk} = \sigma_{kh}$  and  $\epsilon_{hk} = \epsilon_{kh}$ . The first Maxwell equation becomes for absorbing crystals

$$\frac{1}{c}\left[(\epsilon_{11} - 2T\sigma_{11}i)\frac{\partial X}{\partial t} + (\epsilon_{12} - 2T\sigma_{12}i)\frac{\partial Y}{\partial t} + (\epsilon_{13} - 2T\sigma_{13}i)\frac{\partial Z}{\partial t}\right] = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z},$$

or if  $\bar{\epsilon}_{hk}$  be substituted for the complex expression  $(\epsilon_{hk} - 2T\sigma_{hk}i)$  the Maxwell equations can be written

$$\left. \begin{aligned} \frac{1}{c}\left(\bar{\epsilon}_{11}\frac{\partial X}{\partial t} + \bar{\epsilon}_{12}\frac{\partial Y}{\partial t} + \bar{\epsilon}_{13}\frac{\partial Z}{\partial t}\right) &= \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} = \xi, \\ \frac{1}{c}\left(\bar{\epsilon}_{21}\frac{\partial X}{\partial t} + \bar{\epsilon}_{22}\frac{\partial Y}{\partial t} + \bar{\epsilon}_{23}\frac{\partial Z}{\partial t}\right) &= \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = \eta, \\ \frac{1}{c}\left(\bar{\epsilon}_{31}\frac{\partial X}{\partial t} + \bar{\epsilon}_{32}\frac{\partial Y}{\partial t} + \bar{\epsilon}_{33}\frac{\partial Z}{\partial t}\right) &= \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \zeta, \end{aligned} \right\} \quad (5a)$$

$$\frac{1}{c}\frac{\partial u}{\partial t} = \frac{\partial Y}{\partial z} - \frac{\partial Z}{\partial y}, \quad \frac{1}{c}\frac{\partial v}{\partial t} = \frac{\partial Z}{\partial x} - \frac{\partial X}{\partial z}, \quad \frac{1}{c}\frac{\partial w}{\partial t} = \frac{\partial X}{\partial y} - \frac{\partial Y}{\partial x}, \quad (5b)$$

wherein  $\bar{\epsilon}_{hk} = \bar{\epsilon}_{kh}$ .

If for abbreviation the right hand side of equations (5a) be made equal respectively to  $\xi, \eta, \zeta$ , the differential  $\partial X/\partial t, \partial Y/\partial t, \partial Z/\partial t$  can be expressed

in the form

$$\left. \begin{aligned} \frac{\partial X}{\partial t} &= \frac{1}{c} (\bar{a}_{11}\xi + \bar{a}_{12}\eta + \bar{a}_{13}\zeta), \\ \frac{\partial Y}{\partial t} &= \frac{1}{c} (\bar{a}_{21}\xi + \bar{a}_{22}\eta + \bar{a}_{23}\zeta), \\ \frac{\partial Z}{\partial t} &= \frac{1}{c} (\bar{a}_{31}\xi + \bar{a}_{32}\eta + \bar{a}_{33}\zeta), \end{aligned} \right\} \quad (6)$$

in which the complex constants (called polarization constants)  $\bar{a}_{hk} = a_{hk} + ib_{hk}$  are simple determinate functions of  $c^2$  and of the complex quantities  $\bar{\epsilon}_{11} \dots \bar{\epsilon}_{33} \dots$ ; in these equations  $\bar{a}_{hk} = \bar{a}_{kh}$ .

To eliminate the components of the electric force  $X, Y, Z$  differentiate equations (5b) after the time

$$\frac{1}{c} \frac{\partial^2 u}{\partial t^2} = \frac{\partial}{\partial z} \left( \frac{\partial Y}{\partial t} \right) - \frac{\partial}{\partial y} \left( \frac{\partial Z}{\partial t} \right), \quad \frac{1}{c} \frac{\partial^2 v}{\partial t^2} = \frac{\partial}{\partial x} \left( \frac{\partial Z}{\partial t} \right) - \frac{\partial}{\partial z} \left( \frac{\partial X}{\partial t} \right), \quad (7)$$

$$\frac{1}{c} \frac{\partial^2 u}{\partial t^2} = \frac{\partial}{\partial y} \left( \frac{\partial X}{\partial t} \right) - \frac{\partial}{\partial y} \left( \frac{\partial Y}{\partial t} \right),$$

and substitute in these equations the values of  $\partial X/\partial t, \partial Y/\partial t, \partial Z/\partial t$  from equation (6), and obtain the equations

$$\left. \begin{aligned} \frac{\partial^2 u}{\partial t^2} &= \frac{\partial}{\partial x} (\bar{a}_{21}\xi + \bar{a}_{22}\eta + \bar{a}_{23}\zeta) - \frac{\partial}{\partial y} (\bar{a}_{11}\xi + \bar{a}_{12}\eta + \bar{a}_{13}\zeta), \\ \frac{\partial^2 v}{\partial t^2} &= \frac{\partial}{\partial x} (\bar{a}_{11}\xi + \bar{a}_{12}\eta + \bar{a}_{13}\zeta) - \frac{\partial}{\partial z} (\bar{a}_{11}\xi + \bar{a}_{12}\eta + \bar{a}_{13}\zeta), \\ \frac{\partial^2 w}{\partial t^2} &= \frac{\partial}{\partial y} (\bar{a}_{11}\xi + \bar{a}_{12}\eta + \bar{a}_{13}\zeta) - \frac{\partial}{\partial x} (\bar{a}_{21}\xi + \bar{a}_{22}\eta + \bar{a}_{23}\zeta), \end{aligned} \right\} \quad (8)$$

which are free from the components of the electric force and of the electric current.

A particular solution of these equations is

$$u = \mu_1 p, \quad v = \mu_2 p, \quad w = \mu_3 p,$$

$$p = \bar{A} e^{\frac{i2\pi}{T}} \left( t - \frac{v_1 x + v_2 y + v_3 z}{\bar{q}} \right), \quad (9)$$

in which  $\mu_1, \mu_2, \mu_3$  are the direction cosines and  $\bar{A}$  (complex) the amplitude of the polarization vector;  $v_1, v_2, v_3$  the direction cosines of the wave normal and  $\bar{q}$  (complex) the velocity. If in (9) we assume vertical incidence, then

$v_1 = v_2 = 0, v_3 = 1$ ; if we put  $\frac{1}{\bar{q}} = \frac{1 - i\kappa}{q}$ , and  $\lambda = T \cdot q$ , wherein  $q, \kappa$ , and  $\lambda$  are real, then

$$u = \mu_1 \bar{A} e^{-\frac{2\pi\kappa}{\lambda} x} e^{\frac{i2\pi}{T} \left( t - \frac{z}{\lambda} \right)}. \quad (10)$$

This equation states that the amplitude of the wave of light after passage through the path  $\lambda$  (one wave length) has decreased to the extent of  $e^{-2\pi\kappa}$ ;  $\kappa$  is therefore called the absorption index.



For a beam of light entering a second medium the axes of reference may be so chosen that the  $Z$ -axis is normal to the boundary surface while the plane of incidence is the  $XZ$  plane. In this case  $r_1 = \sin i$ ,  $r_2 = 0$ ,  $r_3 = \cos i$ , if the positive  $Z$ -axis points into the second medium and  $i$  is the angle of incidence. In adopting this convention and substituting the values of (9) in (8 and 5a) we obtain, on eliminating  $\mu_1$ ,  $\mu_2$ ,  $\mu_3$  the equation

$$\left. \begin{aligned} (\bar{q}^2 - \bar{a}_{22}) (\bar{q}^2 - \bar{a}_{11} \cos^2 i - \bar{a}_{33} \sin^2 i + 2\bar{a}_{31} \sin i \cos i) \\ = (\bar{a}_{23} \sin i - \bar{a}_{13} \cos i)^2. \end{aligned} \right\} \quad (11)$$

In this equation  $\bar{q}$  and the constants  $\bar{a}_{11} \dots$  are complex quantities. In similar manner we find, by observing that the wave normal and the polarization vector are at right angles, the expression

$$\mu_1 (\bar{q}^2 - \bar{a}_{22}) = \mu_2 (\bar{a}_{23} \cos i \sin i - \bar{a}_{13} \cos^2 i). \quad (12)$$

If the polarization plane include an angle  $\bar{\delta}$  with the plane of incidence ( $\mu_1 = -\cos i \cos \bar{\delta}$ ,  $\mu_2 = \sin \bar{\delta}$ ,  $\mu_3 = \sin i \cos \bar{\delta}$ ) equation (12) can be written

$$\tan \bar{\delta} = \frac{\bar{q}^2 - \bar{a}_{22}}{\bar{a}_{12} \cos i - \bar{a}_{21} \sin i} = \frac{\bar{a}_{12} \cos i - \bar{a}_{21} \sin i}{\bar{q}^2 - \bar{a}_{11} \cos^2 i - \bar{a}_{33} \sin^2 i + 2\bar{a}_{31} \sin i \cos i}. \quad (12a)$$

By means of this equation the azimuth of the wave  $\bar{q}$  can be computed.

*Boundary Conditions.*—On passing from one medium to another, as from air into a crystal plate, light waves encounter at the boundary surface of the plate entirely new conditions. This passage from the system of forces operative in the first medium to that in the second is exceedingly rapid and is accomplished within a very thin film; but it is nevertheless a continuous process since, physically speaking, there are no discontinuities in nature. The boundary surface is an inhomogeneous film in which the dielectric constant passes continuously, though rapidly, from that of the first to that of the second medium. Now in order that the finite current be carried across the boundary the components of the electric and magnetic forces parallel with the boundary surface must be continuous through the boundary; for an infinitely thin film the forces on either side of the film must therefore be equal. If the boundary surface be the  $xy$  plane and the plane of incidence the  $xz$  plane, the general boundary conditions are  $(u)_1 = (u)_2$ ,  $(v)_1 = (v)_2$ ,  $(X)_1 = (X)_2$ ,  $(Y)_1 = (Y)_2$ . For periodic vibrations it is evident that  $(\partial X / \partial t)_1 = (\partial X / \partial t)_2$  and  $(\partial Y / \partial t)_1 = (\partial Y / \partial t)_2$  may be used in place of  $(X)_1 = (X)_2$ ,  $(Y)_1 = (Y)_2$ ; the last equation of (5b) can be written  $(\partial w / \partial t)_1 = (\partial w / \partial t)_2$ , or  $(w)_1 = (w)_2$  for periodic vibrations. Only four of these conditions are independent.

In the case of light waves entering a crystal plate from air, there are two components (magnetic vectors) on the air side of the boundary film,  $u_E$ , that of the incident wave and  $u_R$  that of the reflected wave; on the crystal side there are the components  $u_1$ ,  $u_2$  of the two refracted waves. Equations (8) define the state of the light wave motion at any point and instant. For the boundary film  $Z = 0$ ; in order that in the film the boundary conditions hold for all instants of time, the relations must obtain

$$\frac{v_1}{\bar{q}_1} = \frac{v_2}{\bar{q}_2} = \frac{1}{f} \quad \text{or} \quad \frac{\sin i}{q_0} = \frac{\sin \bar{r}}{\bar{q}} = \frac{1}{f}$$

in which  $i$  is the angle of incidence,  $\bar{r}$  angle<sup>1</sup> of refraction,  $\bar{q}_0$  velocity of light in air,  $q$  wave normal velocity in the crystal medium and  $f$  a constant, real number. Since  $\bar{q}$  is complex,  $\bar{r}$  is also complex. By means of these values equations 11 and 12a can be transformed to read

$$[\bar{d}_{22} + (\bar{d}_{22} - f^2) \tan^2 \bar{r}] [\bar{d}_{11} - 2\bar{d}_{21} \tan \bar{r} + (\bar{d}_{11} - f^2) \tan^2 \bar{r}] \\ = (\bar{d}_{11} - \bar{d}_{22} \tan^2 \bar{r}) (1 + \tan^2 \bar{r}) \quad (13)$$

$$\tan \bar{\delta} = \frac{(f^2 - \bar{d}_{22}) \tan^2 \bar{r} - \bar{d}_{22}}{(\bar{d}_{11} - \bar{d}_{22} \tan^2 \bar{r}) \sqrt{1 + \tan^2 \bar{r}}} = \frac{(f^2 - \bar{d}_{22}) \tan^2 \bar{r} - \bar{d}_{22}}{(f^2 - \bar{d}_{22}) \tan^2 \bar{r} + 2\bar{d}_{21} \tan \bar{r} - \bar{d}_{11}}. \quad (14)$$

In these equations  $\bar{d}_{11}$ ,  $\dots$ ,  $\bar{r}$  and  $\bar{\delta}$  are complex quantities. A complex value of  $\bar{r}$  signifies that the amplitude in the wave is not constant; a complex value of  $\bar{\delta}$ , that there is a phase difference between the amplitudes of the components normal and parallel to the plane of incidence, hence the vibration is elliptic in form.

For the case assumed, namely, a crystal plate surrounded by air, the boundary conditions  $(u)_1 = (u)_0$ ,  $(v)_1 = (v)_0$ ,  $(w)_1 = (w)_0$ ,  $(\partial X / \partial t)_1 = (\partial X / \partial t)_0$  can be written by virtue of equations (9), (5a), (6), and (7).

$$\left. \begin{aligned} (E \cos \epsilon - \bar{R} \cos \bar{\rho}) \cos i &= \bar{D}_1 \cos \bar{\delta}_1 \cos \bar{r}_1 + \bar{D}_2 \cos \bar{\delta}_2 \cos \bar{r}_2, \\ E \sin \epsilon + \bar{R} \sin \bar{\rho} &= \bar{D}_1 \sin \bar{\delta}_1 + \bar{D}_2 \sin \bar{\delta}_2, \\ (E \cos \epsilon + \bar{R} \cos \bar{\delta}) \sin i &= \bar{D}_1 \cos \bar{\delta}_1 \sin \bar{r}_1 + \bar{D}_2 \cos \bar{\delta}_2 \sin \bar{r}_2, \\ (E \sin \epsilon - \bar{R} \sin \bar{\rho}) \sin i \cos i & \\ &= \bar{D}_1 \frac{\sin \bar{r}_1}{\bar{q}_1^2} [\sin \bar{\delta}_1 (\bar{d}_{11} \cos \bar{r}_1 - \bar{d}_{12} \sin \bar{r}_1) + \bar{d}_{12} \cos \bar{\delta}_1] \\ &+ \bar{D}_2 \frac{\sin \bar{r}_2}{\bar{q}_2^2} [\sin \bar{\delta}_2 (\bar{d}_{11} \cos \bar{r}_2 - \bar{d}_{12} \sin \bar{r}_2) + \bar{d}_{12} \cos \bar{\delta}_2], \end{aligned} \right\} \quad (15)$$

in which  $E$ ,  $\bar{R}$ ,  $\bar{D}_1$ ,  $\bar{D}_2$  are the amplitudes of the incident, reflected, and two refracted waves respectively;  $\epsilon$ ,  $\bar{\rho}$ ,  $\bar{\delta}_1$ ,  $\bar{\delta}_2$ , the polarization azimuths;  $q_0$ ,  $q_1$ ,  $\bar{q}_1$ ,  $\bar{q}_2$ , the normal velocities of the waves,  $i$ ,  $-i$ ,  $\bar{r}_1$ ,  $\bar{r}_2$ , the angles between the wave normals and the plate normal.

The last equation of (15) may also be written

$$(E \sin \epsilon - \bar{R} \sin \bar{\rho}) \sin i \cos i = \bar{D}_1 \sin \bar{r}_1 (\cos \bar{r}_1 \sin \bar{\delta} \pm \sin \bar{r}_1 \tan \bar{\delta}_1) \\ + \bar{D}_2 \sin \bar{r}_2 (\cos \bar{r}_2 \sin \bar{\delta}_2 \pm \sin \bar{r}_2 \tan \bar{\delta}_2), \quad (15e)$$

wherein  $\bar{\delta}_k$  is the angle between the refracted wave normal and its ray direction. In this form the equation is more convenient for use in certain computations. In these equations  $i$ ,  $E$ ,  $\epsilon$ ,  $q_0$  of the incident wave are known;  $i$ ,  $q_2$  of the reflected wave; also by computation from (12) and (13)  $\bar{r}_1$ ,  $\bar{r}_2$  and  $\bar{\delta}_1$ ,  $\bar{\delta}_2$  of the refracted waves; unknown are  $\bar{R}$ ,  $\bar{\rho}$  of the reflected wave and  $\bar{D}_1$ ,  $\bar{D}_2$  of the refracted waves.

<sup>1</sup> A dash above a letter is used to signify that the quantity represented may be complex.



The computation of these four quantities from the equations is exceedingly complicated. The introduction of "uniradial azimuths" facilitates the solution considerably. Thus for a certain value of  $\epsilon$  such as  $\epsilon_1$ , all of the refracted light takes the path  $\bar{D}$  ( $\bar{D}_1=1, \bar{D}_2=0$ ), while for another azimuth of the incident plane polarized wave, ( $\bar{D}_2=1, \bar{D}_1=0$ ) and all of the light is refracted along  $\bar{D}_2$ . The values of the uniradial azimuths are given by the equations

$$\left. \begin{aligned} \tan \rho &= -\cos(i + \bar{r}) \tan \bar{\delta} \pm \frac{\sin^2 \bar{r} \cdot \tan \bar{\delta}}{\sin(i - \bar{r}) \cos \bar{\delta}}, \\ \tan \epsilon &= \cos(i - \bar{r}) \tan \bar{\delta} \pm \frac{\sin^2 \bar{r} \cdot \tan \bar{\delta}}{\sin(i + \bar{r}) \cos \bar{\delta}}, \end{aligned} \right\} \quad (16)$$

in which  $\bar{\delta}$  is the angle between the wave normal and the ray direction of the refracted wave.

Let the values of  $E$  and  $\bar{R}$ , computed under the assumption that  $\bar{D}_2=0, \bar{D}_1=1$ , be  $E_1, R_1$ ; similarly for  $\bar{D}_1=0, \bar{D}_2=1$ , let the values be  $E_2, R_2$ . Since equations (15) and (15c) are linear in  $\bar{D}_1$  and  $\bar{D}_2$ , we find on substituting therein first  $\bar{D}_2=0, \bar{D}_1=1$  and then  $\bar{D}_1=0, \bar{D}_2=1$ , and indicating by subscripts, 1 or 2, in each case the proper uniradial azimuth, multiplying the equations thus obtained by  $\bar{D}_1$  and  $\bar{D}_2$  respectively and then adding

$$\begin{aligned} [(E_1 \cos \epsilon_1 \bar{D}_1 + E_2 \cos \epsilon_2 \bar{D}_2) - (\bar{R}_1 \cos \delta_1 \bar{D}_1 + \bar{R}_2 \cos \delta_2 \bar{D}_2)] \cos i \\ = \bar{D}_1 \cos \delta_1 \cos \bar{r}_1 + \bar{D}_2 \cos \delta_2 \cos \bar{r}_2; \end{aligned}$$

therefore

$$\left. \begin{aligned} E \cos \epsilon &= E \bar{p} = E_1 \cos \epsilon_1 \bar{D}_1 + E_2 \cos \epsilon_2 \bar{D}_2 = E \bar{p}_1 \bar{D}_1 + E \bar{p}_2 \bar{D}_2, \\ \bar{R} \cos \rho &= \bar{R} \bar{p} = \bar{R}_1 \cos \rho_1 \bar{D}_1 + \bar{R}_2 \cos \rho_2 \bar{D}_2 = \bar{R} \bar{p}_1 \bar{D}_1 + \bar{R} \bar{p}_2 \bar{D}_2. \end{aligned} \right\} \quad (17)$$

Similarly

$$\left. \begin{aligned} E \sin \epsilon &= E s = E_1 \sin \epsilon_1 \bar{D}_1 + E_2 \sin \epsilon_2 \bar{D}_2 = E s_1 \bar{D}_1 + E s_2 \bar{D}_2, \\ \bar{R} \sin \rho &= \bar{R} s = \bar{R}_1 \sin \rho_1 \bar{D}_1 + \bar{R}_2 \sin \rho_2 \bar{D}_2 = \bar{R} s_1 \bar{D}_1 + \bar{R} s_2 \bar{D}_2, \end{aligned} \right\}$$

in which

$$E s_k = E_k \sin \epsilon_k, E \bar{p}_k = E_k \cos \epsilon_k; \bar{R} s_k = \bar{R}_k \sin \epsilon_k, \bar{R} \bar{p}_k = \bar{R}_k \cos \epsilon_k.$$

If the amplitude and polarization azimuth of the incident wave be given and hence  $E s_1, E \bar{p}_1, \delta_k$  and  $r_k$ , the corresponding values of the reflected wave can be computed from equations (17) and put into the form

$$\left. \begin{aligned} (E \bar{p}_1 E s_2 - E \bar{p}_2 E s_1) \bar{R} s_1 &= (\bar{R} s_1 E s_2 - \bar{R} s_2 E s_1) E \bar{p} - (\bar{R} s_1 E \bar{p}_2 - \bar{R} s_2 E \bar{p}_1) E s, \\ (E \bar{p}_1 E s_2 - E \bar{p}_2 E s_1) \bar{R} \bar{p} &= (\bar{R} \bar{p}_1 E s_2 - \bar{R} \bar{p}_2 E s_1) E \bar{p} - (\bar{R} \bar{p}_1 E \bar{p}_2 - \bar{R} \bar{p}_2 E \bar{p}_1) E s, \end{aligned} \right\} \quad (18)$$

which is deduced by eliminating  $\bar{D}_1$  and  $\bar{D}_2$  from equations (17). The values of  $\bar{R}_s$  and  $\bar{R}_p$  are complex.

If the incident wave be plane-polarized the complex values of  $\bar{R}_s/E s, \bar{R}_p/E \bar{p}$ , and  $\bar{R}_s/\bar{R}_p$  show that phase differences exist between the three waves and that therefore the reflected wave is in general elliptically polarized. If

we put

$$\frac{Rs}{Rp} = \tan \rho' = \tan \psi e^{i\Delta} = \tan \psi (\cos \Delta + i \sin \Delta) \quad (19)$$

$$= \frac{(\bar{R}s_1 E s_2 - \bar{R}s_2 E s_1) - (\bar{R}s_1 E p_2 - \bar{R}s_2 E p_1) \tan \epsilon}{(\bar{R}p_1 E s_2 - \bar{R}p_2 E s_1) - (\bar{R}p_1 E p_2 - \bar{R}p_2 E p_1) \tan \epsilon},$$

in which  $\tan \epsilon = Es/Ep$  and the azimuth angle  $\psi$  is real, then  $\Delta$  is the relative phase difference of the components normal and parallel to the plane of incidence. By equating the real and imaginary parts of this equation to zero, we obtain equations from which  $\psi$  and  $\Delta$  can be computed. The equation shows that for a certain angle of incidence the phase difference may be  $\pi/2$ ; for this angle of incidence the reflected wave is plane-polarized. If  $\epsilon = 45^\circ$ , then this angle of incidence,  $i$ , is called the principal angle of incidence and the angle  $\Psi$  the principal azimuth. From these two angles it is possible in certain cases (especially isotropic bodies) to compute the refractive index and the absorption index of the reflecting medium. Different methods have been devised for ascertaining these angles; practically all the methods available for ascertaining the refractive and absorption indices of absorbing substances are based on the above equations or certain modifications of the same, deduced on the basis of simplifying assumptions.

#### VERTICAL INCIDENCE.

In case the angle of incidence is zero,  $i = 0$ , the above equations reduce to the following:

$$(\bar{q}^2 - \bar{a}_{22})(\bar{q}^2 - \bar{a}_{11}) = \bar{a}_{12}^2, \quad (11')$$

$$\tan \bar{\delta} = \frac{\bar{q}^2 - \bar{a}_{22}}{\bar{a}_{12}} = \frac{\bar{a}_{12}}{\bar{q}^2 - \bar{a}_{11}}, \quad (12a')$$

$$E \cos \epsilon - R \cos \rho = D_1 \cos \bar{\delta}_1 + D_2 \cos \bar{\delta}_2,$$

$$E \sin \epsilon + R \sin \rho = D_1 \sin \bar{\delta}_1 + D_2 \sin \bar{\delta}_2, \quad (15', 15'e)$$

$$q_0 E \cos \epsilon + q_0 R \cos \rho = \bar{q}_1 D_1 \cos \bar{\delta}_1 + \bar{q}_2 D_2 \cos \bar{\delta}_2,$$

$$q_0 E \sin \epsilon - q_0 R \sin \rho = \bar{q}_1 D_1 \sin \bar{\delta}_1 + \bar{q}_2 D_2 \sin \bar{\delta}_2.$$

For uniradial azimuths we find for  $\bar{\delta}_1$ ,

$$Ep_1 - Rp_1 = \cos \bar{\delta}_1,$$

$$Es_1 + Rs_1 = \sin \bar{\delta}_1,$$

$$Ep_1 + Rp_1 = \frac{\bar{q}_1}{q_0} \cos \bar{\delta}_1,$$

$$Es_1 - Rs_1 = \frac{\bar{q}_1}{q_0} \sin \bar{\delta}_1.$$



Therefore

$$2q_0 E p_1 = (q_0 + \bar{q}_1) \cos \bar{\delta}_1, \quad 2q_0 E s_1 = (q_0 + \bar{q}_1) \sin \bar{\delta}_1; \\ 2q_0 R p_1 = (\bar{q}_1 - q_0) \cos \delta_1, \quad 2q_0 R s_1 = (q_0 - \bar{q}_1) \sin \delta_1.$$

Similarly

$$2q_0 E p_2 = (q_0 + \bar{q}_2) \cos \bar{\delta}_2, \quad 2q_0 E s_2 = (q_0 + \bar{q}_2) \sin \bar{\delta}_2; \\ 2q_0 R p_2 = (\bar{q}_2 - q_0) \cos \delta_2, \quad 2q_0 R s_2 = (q_0 - \bar{q}_2) \sin \delta_2.$$

On substituting these values in equation (19), we obtain

$$\frac{\bar{R}s}{\bar{R}p} = \frac{2q_0(\bar{q}_2 - \bar{q}_1) \tan \bar{\delta}_1 \tan \bar{\delta}_2 - [(q_0 - \bar{q}_1)(q_0 + \bar{q}_2) \tan \bar{\delta}_1 - (q_0 - \bar{q}_2)(q_0 + \bar{q}_1) \tan \bar{\delta}_2] \tan \epsilon}{(q_0 - \bar{q}_2)(q_0 + \bar{q}_1) \tan \bar{\delta}_1 - (q_0 - \bar{q}_1)(q_0 + \bar{q}_2) \tan \bar{\delta}_2 - 2q_0(q_2 - \bar{q}_1) \tan \epsilon}. \quad (19')$$

The right-hand side of this equation is complex; therefore, plane polarized light incident on a crystal plate of an absorbing crystal generally becomes on reflection elliptically polarized. The equations are, however, so complicated, that progress is best made by the solution of a few simple cases in which the crystallographic symmetry relations prescribe certain types of vibration.

For the special case that the plane of incidence is a plane of symmetry the equations become noticeably simpler; this assumption is valid for isotropic, uniaxial, and certain sections of orthorhombic crystals because in these the positions of the principal axes of the polarization and absorption surfaces of reference coincide as they are fixed by the symmetry relations. In general these axes do not coincide and the surface of reference can be represented only by the use of complex quantities. On the assumption that the plane of incidence is a plane of symmetry let  $\theta$  be the angle between the  $Z'$  axis (normal to the plate) and the  $Z$  principal axis. The equations defining the complex polarization constants then obtain

$$\bar{a}_{11} = a_{11} + ib_{11} = \bar{a}^2 \cos^2 \theta + \bar{c}^2 \sin^2 \theta,$$

$$\bar{a}_{22} = a_{22} + ib_{22} = \bar{b}^2,$$

$$\bar{a}_{33} = a_{33} + ib_{33} = \bar{a}^2 \sin^2 \theta + \bar{c}^2 \cos^2 \theta,$$

$$\bar{a}_{23} = a_{23} + ib_{23} = 0,$$

$$\bar{a}_{31} = a_{31} + ib_{31} = (\bar{a}^2 - \bar{c}^2) \cos \theta \sin \theta,$$

$$\bar{a}_{12} = a_{12} + ib_{12} = 0.$$

In these equations  $\bar{a}_{11}$ ,  $\dots$  and  $\bar{a}$ ,  $b$ ,  $\bar{c}$  are complex quantities. On substituting these values in equations (10'), (11'a) and (15) we find

$$(q^2 - \bar{a}_{11})(q^2 - \bar{a}_{22}) = 0 \quad \text{or} \quad \bar{q}_2^2 = \bar{a}_{11} \quad \bar{q}_1^2 = \bar{a}_{22},$$

$$\delta_1 = 0, \quad \delta_2 = \frac{\pi}{2},$$

$$\epsilon_1 = 0, \quad \epsilon_2 = \frac{\pi}{2}.$$

The refracted waves  $\delta_1$ ,  $\delta_2$  are thus plane-polarized. Equations (18) reduce to the form

$$\frac{\bar{R}s}{\bar{E}s} = \frac{Rs_1 E p_2}{E p_2 E s_1} = \frac{Rs_1}{E s_1} = \frac{q_0 - \bar{q}_1}{q_0 + \bar{q}_1}.$$

But from equation (10)

$$\frac{\bar{q}_1}{q_0} = \frac{q_1}{q_0(1 - i\kappa)} = \frac{1}{n_1(1 - i\kappa)};$$

accordingly

$$\frac{\bar{R}s}{\bar{E}s} = \frac{n_1 - 1 - in_1\kappa_1}{n_1 + 1 - in_1\kappa_1}. \quad (20)$$

The right-hand side of this equation is a complex quantity and of the form

$$\frac{a + ib}{A + iB} = \frac{aA + bB + i(bA - aB)}{A^2 + B^2} = f + ig.$$

This in turn may be considered equivalent to the expression

$$(P + iQ)e^{i\tau} = (P + iQ)(\cos \tau + i \sin \tau) \\ = P \cos \tau - Q \sin \tau + i(P \sin \tau + Q \cos \tau).$$

If now

$$P = r \cos \Delta,$$

$$Q = -r \sin \Delta,$$

the amplitude may be written for  $E s = 1$

$$R s = r_1 \cos (\tau - \Delta_1) + i r_1 \sin (\tau - \Delta_1) = f + ig = r_1 e^{i(\tau - \Delta_1)} \quad (21)$$



Therefore

$$f = r_1 \cos(\tau - \Delta_1),$$

$$g = r_1 \sin(\tau - \Delta_1).$$

Hence

$$r_1^2 = f^2 + g^2$$

$$\tan(\tau - \Delta_1) = \frac{g}{f}$$

The expression  $f^2 + g^2$  is most readily obtained by multiplying  $f + ig$  by its complex conjugate  $(f - ig)$ . Accordingly the intensity of the reflected light which is proportional to the square of the amplitude  $r_1^2$  is

$$\frac{Irs}{Is} = \frac{(n_1 - 1)^2 + n_1^2 \kappa_1^2}{(n_1 + 1)^2 + n_1^2 \kappa_1^2} = \frac{\left(1 - \frac{1}{n_1}\right)^2 + \kappa_1^2}{\left(1 + \frac{1}{n_1}\right)^2 + \kappa_1^2}. \quad (22)$$

The phase difference is given by

$$\tan(\tau - \Delta_1) = \frac{bA - aB}{aA + bB} = \frac{-2n_1\kappa_1}{n_1^2 - 1 + n_1\kappa_1}. \quad (23)$$

Similarly the amplitude of the component parallel with the plane of incidence is

$$\frac{Rp}{Ep} = \frac{Rp_2}{Ep_2} = \frac{\bar{q}_2 - q_0}{\bar{q}_2 + q_0} = -\frac{n_2 - 1 - in_2\kappa_2}{n_2 + 1 - in_2\kappa_2}. \quad (24)$$

The intensity is

$$\frac{Irp}{Ip} = \frac{(n_2 - 1)^2 + n_2^2 \kappa_2^2}{(n_2 + 1)^2 + n_2^2 \kappa_2^2}. \quad (25)$$

The phase difference is

$$\tan(\tau - \Delta_2) = \frac{-2n_2\kappa_2}{n_2^2 - 1 + n_2^2 \kappa_2^2}. \quad (26)$$

By division of (20) by (24) an expression for the amplitude ratio is obtained

$$\frac{Rs}{Rp} = -\frac{(n_1 - 1 - in_1\kappa_1)(n_2 + 1 - in_2\kappa_2)}{(n_1 + 1 - in_1\kappa_1)(n_2 - 1 - in_2\kappa_2)} \cdot \frac{Es}{Ep}. \quad (27)$$

This is a complex quantity and indicates that a phase difference exists between the two components (parallel and normal to plane of incidence) of the reflected light; the reflected light is in general elliptically polarized. In case the azimuth of the plane polarized incident light  $\epsilon$  coincides with either  $\epsilon_1$  or  $\epsilon_2$ , the reflected light is plane-polarized. The azimuths for which the reflected light is plane-polarized occur at intervals of  $90^\circ$ .

The intensity ratio of the components of the reflected light is found by division of (21) by (25)

$$\frac{Irs}{Irp} = \frac{[(n_1 - 1)^2 + n_1^2 \kappa_1^2][(n_2 + 1)^2 + n_2^2 \kappa_2^2]}{[(n_1 + 1)^2 + n_1^2 \kappa_1^2][(n_2 - 1)^2 + n_2^2 \kappa_2^2]} \cdot \frac{Is}{Ip}. \quad (28)$$

The phase difference for  $Ep = Es$  or  $\tan \epsilon = 1$  is  $\Delta_1 - \Delta_2$  or

$$\tan (\Delta_1 - \Delta_2) = \frac{2n_2 \kappa_2 (n_1^2 - 1 + n_1^2 \kappa_1^2) - 2n_1 \kappa_1 (n_2^2 - 1 + n_2^2 \kappa_2^2)}{(n_1^2 - 1 + n_1^2 \kappa_1^2)(n_2^2 - 1 + n_2^2 \kappa_2^2) + 4n_1 \kappa_1 n_2 \kappa_2}. \quad (29)$$

#### TRANSPARENT MEDIA.

In order to realize clearly the effects of absorption phenomena it is essential to ascertain first the behavior of non-absorbing media, then to pass to the more complex problem of absorbing bodies.

*Isotropic Substances.*—For non-absorbing bodies  $\kappa = 0$ ; in this case equation (22) reduces to the ordinary Fresnel expression for the intensity of rays reflected from an isotropic plate

$$\frac{Ir}{I} = \left( \frac{n - 1}{n + 1} \right)^2. \quad (30)$$

TABLE 2.

In this table are listed the relative intensities of light reflected at vertical incidence from polished surfaces of substances of given refractive indices. Thus a plate of refractive index 2.1 reflects 0.1259 of the incident light.

$n$	$\frac{Ir}{I}$	$n$	$\frac{Ir}{I}$	$n$	$\frac{Ir}{I}$	$n$	$\frac{Ir}{I}$
1.0	0	1.6	.0533	2.2	.1406	2.8	.2244
1.1	.0023	1.7	.0676	2.3	.1552	2.9	.2374
1.2	.0083	1.8	.0816	2.4	.1696	3.0	.2500
1.3	.0170	1.9	.0963	2.5	.1836	4.0	.3600
1.4	.0278	2.0	.1111	2.6	.1975	5.0	.4444
1.5	.0400	2.1	.1259	2.7	.2111	10.0	.6667



This equation shows that the higher the refractive index the more light is reflected. The relative intensities for a series of refractive indices are listed in Table 2.

Equation (23) reduces for  $\kappa=0$  to  $\tan(\tau-\Delta_1)=0$ ; in other words, there is no change in phase on reflection. Vertically incident plane-polarized light is reflected as plane-polarized light without change of phase and with no change in azimuth of polarization plane. (Equation (27) for  $n_1=n_2$  and  $\kappa_1=\kappa_2=0$ .)

*Birefracting Media.*—For a birefracting transparent medium ( $\kappa_1=\kappa_2=0$ ); equation (28) reduces to

$$\frac{Irs}{Irp} = \left( \frac{n_1 - 1}{n_1 + 1} \right)^2 \left( \frac{n_2 + 1}{n_2 - 1} \right)^2 \quad (31)$$

$$= 1 - \frac{4(n_2 - n_1)}{(n_1 + 1)(n_2 - 1)} + \frac{4(n_2 - n_1)^2}{(n_1 + 1)^2(n_2 - 1)^2}.$$

The third term of the last expression is negligible for weakly birefracting substances. The change in intensity ratio with change in least refractive index  $n_1$  and with birefringence ( $n_2 - n_1$ ) is shown in Table 3 and presented graphically in Fig 2.

TABLE 3.

In this table are given the relative intensities of the two components, normal and parallel to the plane of incidence, of light waves reflected from a transparent birefracting crystal surface whose low refractive index is  $n_1$  and whose birefringence is  $n_2 - n_1$ . Thus for a crystal plate, whose least refractive index is 1.8 and whose birefringence is 0.040, the ratio of the intensities of the two reflected components is 0.932.

$n_2 - n_1$	0.005	0.010	0.020	0.030	0.040	0.050	0.075	0.100	0.150	0.200
$n_1$										
1.2	.960	.919	.845	.794	.723	.673	.568	.487	.374	.298
1.4	.979	.960	.917	.888	.854	.824	.755	.695	.598	.522
1.6	.989	.975	.953	.928	.908	.886	.837	.793	.716	.652
1.8	.991	.982	.964	.948	.932	.916	.881	.848	.787	.734
2.0	.993	.986	.973	.962	.949	.937	.908	.882	.833	.789
2.5	.995	.991	.984	.977	.970	.963	.945	.929	.898	.869
3.0	.998	.995	.990	.986	.980	.976	.963	.953	.931	.911
4.0	.998	.996	.995	.992	.989	.986	.982	.974	.962	.951
5.0	.999	.998	.997	.995	.993	.992	.988	.985	.977	.968

The ratio of the amplitudes (equation 27) becomes

$$\frac{Rs}{Rp} = - \frac{(n_1 - 1)(n_2 + 1)}{(n_1 + 1)(n_2 - 1)} \cdot \frac{Es}{Ep}. \quad (32)$$

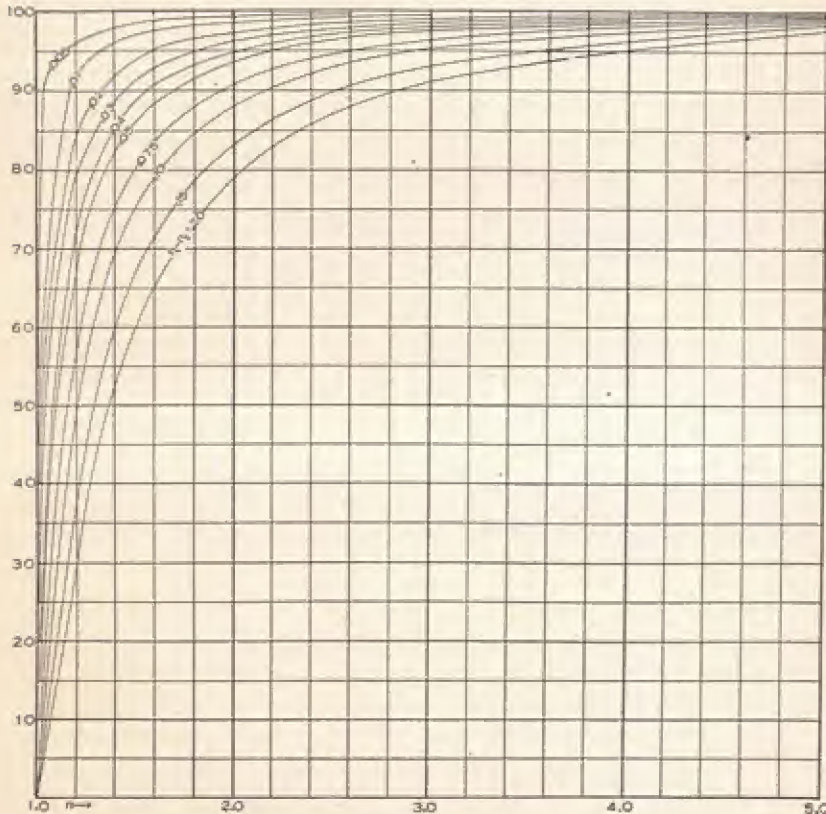


FIG. 2. The curves in this figure indicate the change in the percentage intensity ratio (ordinates) of the two components of normally reflected light with change in the least refractive index  $n_1$  (abscissæ) and in the birefringence ( $n_2 - n_1$ ) (curves) of a crystal plate.

The fact that this is a real quantity proves that there is no phase difference between the two components; the phenomena observed on such plates are due therefore entirely to a difference in the amplitudes of the reflected wave components. The reflected light is plane-



polarized; the azimuth  $\rho$  of the plane of polarization of the reflected wave is for  $E_s = E_\rho$  or  $\tan \epsilon = 1$  (equation 32)

$$\tan \rho = \frac{R_s}{R_p} = -1 + \frac{2(n_2 - n_1)}{(n_1 + 1)(n_2 - 1)} \quad (33)$$

There is therefore on reflection a rotation of the plane of polarization through the angle  $(\epsilon - \rho)$ . For the ordinary case  $\tan \epsilon = 1$  ( $\epsilon = 45^\circ$ ), we find from (33)

$$\tan (\epsilon - \rho) = \frac{1 - \tan \rho}{1 + \tan \rho} = \frac{n_1 n_2 - 1}{n_2 - n_1} \quad (34)$$

The angular amounts of rotation on reflection of vertically incident plane-polarized light for  $\epsilon = 45^\circ$  and for different refractive indices and birefringences are listed in Table 4 and are presented graphically in Fig. 3.

TABLE 4.

In this table is given the angular rotation, on reflection from a crystal plate, of the plane of polarization of vertically incident light waves whose plane of polarization includes an angle of  $45^\circ$  with the vibration directions of the crystal plate.

$n_2$	1.2	1.4	1.6	1.8	2.0	2.5	3.0	4.0	5.0
$n_2 - n_1$									
.005	0° 39'	0° 18'	0° 11'	0° 08'	0° 05'	0° 03'	0° 02'	0° 01'	0° 01'
.010	1 16	0 35	0 22	0 15	0 11	0 06	0 04	0 02	0 01
.020	2 28	1 09	0 43	0 30	0 22	0 13	0 08	0 05	0 03
.030	3 36	1 43	1 04	0 45	0 35	0 19	0 13	0 07	0 04
.040	4 41	2 15	1 25	0 59	0 44	0 26	0 17	0 09	0 06
.050	5 42	2 47	1 45	1 14	0 55	0 32	0 21	0 11	0 07
.075	8 03	4 02	2 33	1 48	1 22	0 48	0 31	0 17	0 10
.100	10 08	5 11	3 19	2 22	1 47	1 03	0 41	0 22	0 14
.150	13 36	7 18	4 46	3 26	2 36	1 32	1 01	0 33	0 21
.200	16 23	9 10	6 04	4 24	3 19	2 00	1 20	0 43	0 28

Figures 2 and 3 indicate clearly that there are two distinct methods for detecting anisotropism in birefracting, transparent media by means of vertically incident light; either intensity differences between the two components parallel and normal to the plane of incidence may be utilized (equation 31) or the rotation of the plane of polarization (equation 34).

Differences of intensity are detected ordinarily by photometric

methods which involve direct comparison of two adjacent illuminated fields (half shade principle). The accuracy of a single setting obtainable with such methods is dependent on the sensitiveness of

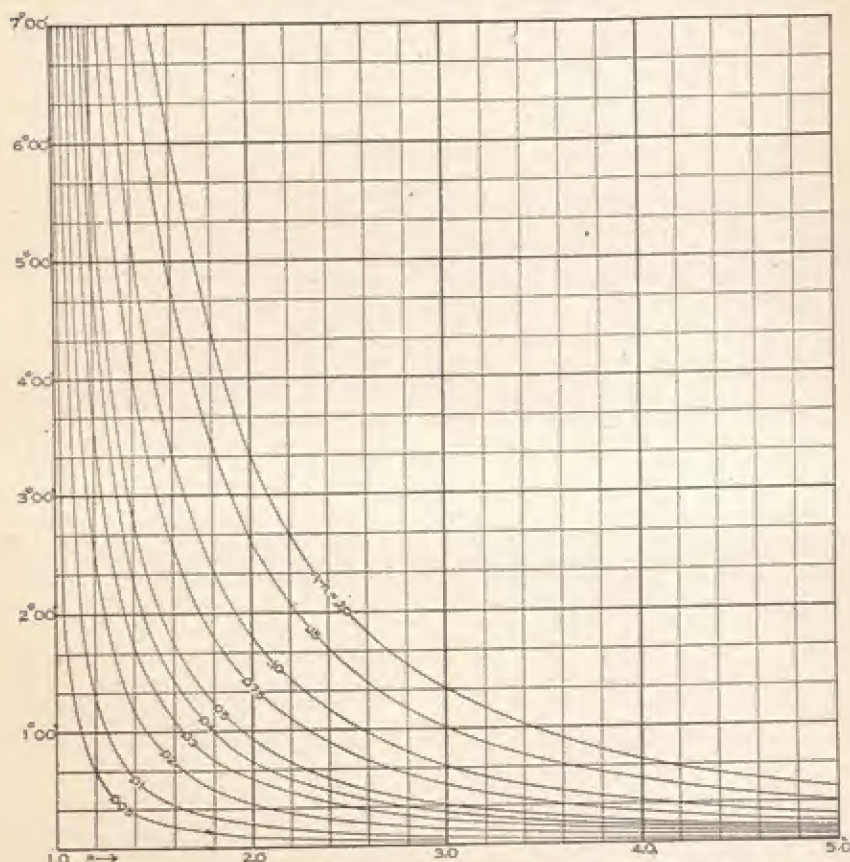


FIG. 3. In this figure is indicated the angular rotation in degrees (ordinates) of the plane of polarization of vertically incident, plane-polarized light of azimuth  $\epsilon = 45^\circ$  on reflection from a crystal plate of least refractive index  $n_1$  (abscissæ) and of birefringence  $n_2 - n_1$  (curves).

the eye, or on the least perceptible difference in light intensity under the conditions of observation. An extended series of measurements by Koenig and Brodhun<sup>3</sup> on the least perceptible increment (dif-

<sup>3</sup> *Sitzungsberichte d. Acad. d. Wissensch. Berlin*, July 26, 1888. "Gesammelte Abhandl. und Physiolog. Optik" (A. König), 116-143.



ference limen) for different intensities and different wave-lengths shows that for an intermediate intensity of illumination differences of intensity 1.6 to 2.0 per cent. can just be detected; for low (below 50 m.c.) and high (above 100,000 m.c.) intensities, the least perceptible difference in intensity is greater. Under ordinary conditions of illumination we may assume that 2 per cent. difference in illumination intensity is about the limit perceptible to the eye. This means that in order to be recognized by the eye there must be a difference of about 2 per cent. in intensity of light reflected by the two components. To find the birefringence ( $n_2 - n_1$ ) required to produce this least perceptible difference in intensities of reflected light, namely, 2 per cent., we may without sensible error use only the first two terms of equation (31) and transform it to read

$$n_2 - n_1 = \frac{0.02 (n_1 + 1)(n_2 - 1)}{4}, \quad (35)$$

from which the necessary birefringence ( $n_2 - n_1$ ) for the different refractive indices  $n_1$  can be computed. These are listed in Table 5.

TABLE 5.

In this table is given the least degree of birefringence of a crystal plate which on the reflection of vertically incident light produces a detectable difference in intensity of the two waves polarized at planes normal one to the other.

$n_1$	$n_2 - n_1$	$n_1$	$n_2 - n_1$	$n_1$	$n_2 - n_1$
1.1	.001	1.6	.007	2.5	.026
1.2	.002	1.7	.009	3.0	.040
1.3	.004	1.8	.011	4.0	.075
1.4	.005	1.9	.013	5.0	.120
1.5	.006	2.0	.015	10.0	.440

This table shows that for very low-refracting, non-absorbing substances only a relatively slight increase in refractive index (birefringence weak) is necessary to produce the required perceptible difference in intensity; for minerals of medium refringence and birefringence, such as quartz, the difference limen increases, but the birefringence required is still medium to weak; for highly refracting media the required difference in refractive indices increases rapidly. The essential feature to note, however, is that minerals of medium

refractive index but weak birefringence, such as apatite, do not exhibit the required difference in intensity (2 per cent.) of the reflected components; and that, if the observations were limited to this phenomenon, the anisotropism of the mineral would escape detection. In other words the sensitiveness of methods based on the relative intensity of the two reflected components is far below that for detecting anisotropism in transmitted light. Thus it is not difficult in ordinary thin sections (0.02 mm. thick) to detect a path difference of  $2\mu$ ; this corresponds to a birefringence of 0.0001. For a mineral of refractive index 1.6 the least detectible birefringence by reflected intensities is about 0.070. In other words the methods of transmitted light are 50 or more times as sensitive as the methods based on intensity differences of reflected intensities. This follows as a direct result of the lack of sensitiveness of the eye in detecting differences in intensity of adjacent fields.

Methods based on equation (34) depend on the ability of the eye to determine the position of complete darkness (intensity of illumination = 0); the chief factor which limits the degree of precision attainable by this method is the threshold limit of vision or the least quantity of light which the eye can detect. Experience has shown that it is not difficult to detect, under ordinary conditions of illumination with the aid of certain devices, a rotation of the plane of polarization through  $5'$ . Substituting this value in equation (34) we obtain

$$n_2 - n_1 = 0.0015(n_1 + 1)(n_2 - 1). \quad (36)$$

A comparison of this equation with (35) shows that this method is at least three times as sensitive as the first. The precision attainable by the second method is dependent, moreover, on the sensitiveness of the device employed to detect a rotation of the plane of polarization. Without any special device an error of  $\frac{1}{2}^\circ$  is readily possible. In this case the accuracy of this method is considerably less than that of the intensity difference method. In case a device is used which shows a perceptible difference for a rotation of  $\frac{1}{4}^\circ$  the precision attainable by the two methods is identical. The accuracy of the second method can, however, be increased by using a very intense source of light. The several methods for determining



positions of extinction have been discussed in detail by the writer<sup>4</sup> and the conclusion reached that the bi-quartz-wedge-plate is the most sensitive device available for the purpose. With it the sensitiveness can be varied to meet the conditions of illumination. M. Berek<sup>5</sup> has shown that with the bi-quartz-wedge-plate a precision of 0.5' can be attained under the most favorable conditions of observation.

#### ABSORBING MEDIA.

In the foregoing section the phenomena produced on reflection from transparent crystal plates are treated in some detail and the factors underlying the methods for the detection of anisotropism and for the measurement of the birefringence and the refractive indices are discussed. The introduction of the absorption index into the equations carries with it a series of complications which render the relations less easy to follow, but which are, as a result, the more interesting.

TABLE 6.

In this table the intensity is given of the light reflected, at vertical incidence, from the surface of an isotropic substance of refractive index  $n$  and absorption index  $\kappa$ . Thus a plate of refractive index 2.0 and absorption index 1.32 reflects 50 per cent. of the incident light.

$I_r/I_i$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
$n$									
0.1	—	—	—	—	—	—	3.51	8.9	16.7
0.2	—	—	—	—	—	3.74	6.06	8.0	12.8
0.3	—	—	.52	1.86	2.00	3.82	5.07	6.92	10.7
0.4	—	.5	1.43	2.17	2.81	3.57	4.67	6.13	9.35
0.5	—	1.0	1.56	2.08	2.78	3.32	4.21	5.57	8.43
0.75	.69	1.1	1.47	1.97	2.29	2.79	3.51	4.70	6.92
1.0	.67	1.0	1.31	1.63	2.00	2.45	3.05	4.00	6.00
2.0	—	.5	.78	1.04	1.32	1.66	2.10	2.78	4.22
3.0	—	—	.36	.67	.94	1.25	1.63	2.21	3.41
4.0	—	—	—	.32	.66	.97	1.33	1.85	2.90
5.0	—	—	—	—	.40	.75	1.11	1.60	2.56
7.5	—	—	—	—	—	.21	.69	1.17	2.03
10.0	—	—	—	—	—	—	.35	.89	1.67
For $\kappa = 0$									
$n_1$ .....	.52	.38	.29	.23	.17	.13	.09	.06	.03
$n_2$ .....	1.93	2.62	3.43	4.44	6.04	7.90	11.3	17.9	38.2

<sup>4</sup> *Am. Jour. Sci.* (4), 26, 377-378, 1908. Carnegie Institution of Washington, Publication 158, p. 139, 1911.

<sup>5</sup> *Neues Jahrbuch für Mineralogie etc.*, Beilage Band 33, pp. 583-661, 1912.

*Isotropic, Absorbing Media.*—For such substances  $n_1 = n_2$ ,  $\kappa_1 = \kappa_2$ . The intensity of the reflected light is (equation 22)

$$\frac{Irs}{Is} = \frac{(n-1)^2 + n^2\kappa^2}{(n+1)^2 + n^2\kappa^2}. \quad (37)$$

In order to form a clear picture of the relative influence of the

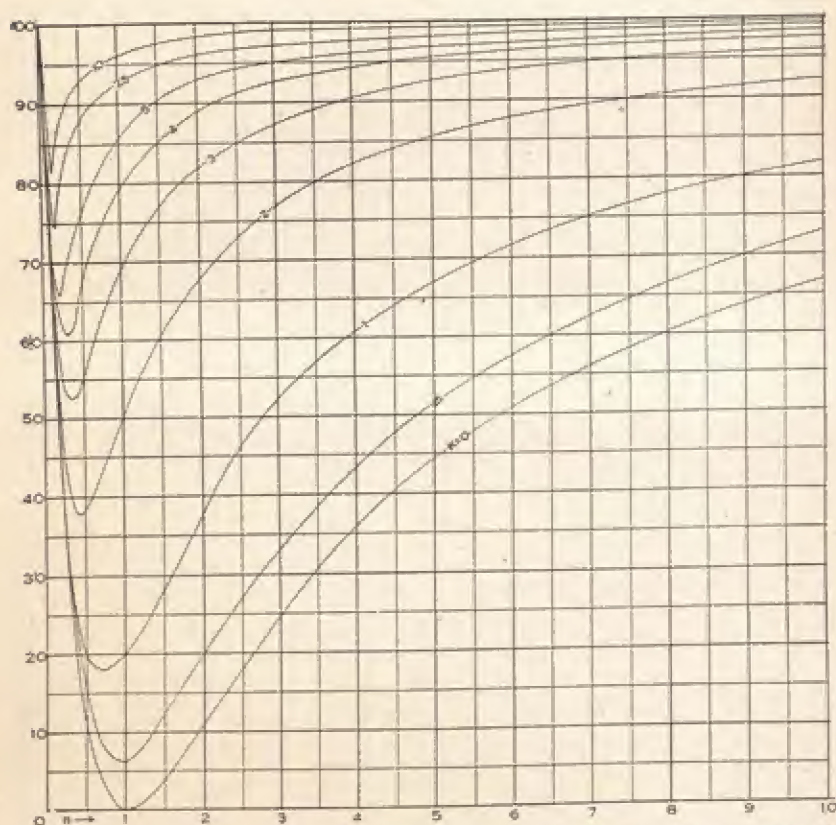


FIG. 4. The percentage (ordinates) of normally incident light reflected from a plate of refractive index  $n$  (abscissae) and absorption index  $\kappa$  (curves) is given in this figure.

refractive index and the absorption index on the reflecting power of an anisotropic, absorbing crystal surface, a series of values computed by means of equation (37) are listed in Table 6 and are rep-





because it shows that high reflecting power (metallic or sub-metallic luster) may arise either from high absorption index as in Na, Ag; or from high refractive index, as in Si and galena; or from both high refractive index and high absorption index, as in Ir, Zn. The curves of these figures show that in general an increase in the absorption index is much more effective in increasing the reflecting power of the substance than the same amount of increase in the refractive index.

The ratio of the amplitude components  $R_s, R_p$  is (equation 27)

$$\frac{R_s}{R_p} = -\frac{E_p}{E_s}.$$

For  $E_p = E_s$  this reduces to  $-1$  and indicates a phase difference of  $\pi$  between the incident and reflected waves. The phase difference between the two components is (equation 29)

$$\tan (\Delta_2 - \Delta_1) = 0.$$

Therefore plane-polarized, vertically incident light is still plane-polarized after reflection from an isotropic absorbing body.

*Birefracting, Biabsorbing Media.*—The intensity ratio of the reflected components from a birefracting, biabsorbing crystal plate is stated by equation (28) which can be written for  $E_s = E_p$  or  $\tan \epsilon = 1$

$$\frac{I_{rs}}{I_{rp}} = 1 - \frac{4[(n_1 - n_2)(1 + n_1 n_2) + n_1 n_2(n_2 \kappa_1^2 - n_1 \kappa_2^2)]}{[(n_1 + 1)^2 + n_1^2 \kappa_1^2][(n_2 - 1)^2 + n_2^2 \kappa_2^2]}. \quad (38)$$

This equation shows that for weakly birefracting substances ( $n_1$  approximately equal to  $n_2$ ) the intensity ratio depends on the difference of the squares of the absorption indices. For substances with weak biabsorption the intensity ratio depends primarily on the difference of the refractive indices. This indicates that an increase in the biabsorption is more effective in increasing the degree of anisotropism than the same amount of increase in birefringence.

The phase difference between one of the components and that of the incident beam is given by equation (23). Series of values computed by means of this equation are listed in Table 7 and are presented in graphical form in Fig. 6 in which the refractive indices



are the abscissæ, the ordinates the angles ( $\tau - \Delta_1$ ), and the curves the absorption indices. The curves show clearly that for substances with high refractive indices and high or low absorption indices the

TABLE 7.

In this table are listed the phase differences between the vertically incident beam and one of the components reflected from a plate of refractive index  $n$  and absorption index  $\kappa$ . Thus for a plate of refractive index 1.5 and absorption index 0.2, the phase difference is  $24^\circ 07'$ .

$\kappa$	0.2	0.4	0.6	0.8	1.0	1.5
$n$						
0.2	$-4^\circ 47'$	$-9^\circ 32'$	$-14^\circ 14'$	$-18^\circ 54'$	$-23^\circ 52'$	$-34^\circ 36'$
0.4	$-10^\circ 52'$	$-21^\circ 27'$	$-31^\circ 31'$	$-41^\circ 00'$	$-49^\circ 37'$	$-68^\circ 12'$
0.6	$-21^\circ 00'$	$-39^\circ 30'$	$-54^\circ 40'$	$-66^\circ 52'$	$-76^\circ 52'$	$-85^\circ 15'$
0.8	$-45^\circ 30'$	$-68^\circ 03'$	$-82^\circ 18'$	$-87^\circ 47'$	$-80^\circ 05'$	$-65^\circ 46'$
1.0	$84^\circ 18'$	$78^\circ 42'$	$73^\circ 18'$	$68^\circ 12'$	$63^\circ 27'$	$53^\circ 08'$
1.5	$24^\circ 07'$	$36^\circ 42'$	$41^\circ 10'$	$41^\circ 44'$	$40^\circ 36'$	$35^\circ 30'$
2.0	$14^\circ 13'$	$23^\circ 45'$	$28^\circ 24'$	$29^\circ 55'$	$29^\circ 45'$	$26^\circ 34'$
3.0	$8^\circ 10'$	$14^\circ 16'$	$17^\circ 45'$	$19^\circ 13'$	$19^\circ 36'$	$18^\circ 26'$
4.0	$5^\circ 51'$	$10^\circ 19'$	$13^\circ 01'$	$14^\circ 13'$	$14^\circ 28'$	$13^\circ 14'$
5.0	$4^\circ 35'$	$8^\circ 08'$	$10^\circ 18'$	$11^\circ 19'$	$11^\circ 32'$	$10^\circ 36'$
7.5	$2^\circ 59'$	$5^\circ 20'$	$6^\circ 40'$	$7^\circ 29'$	$7^\circ 40'$	$7^\circ 03'$
10.0	$2^\circ 01'$	$3^\circ 59'$	$5^\circ 04'$	$5^\circ 36'$	$5^\circ 45'$	$5^\circ 18'$

$\kappa$	2.0	3.0	4.0	5.0	7.5	10.0
$n$						
0.2	$-45^\circ 00'$	$-63^\circ 27'$	$-78^\circ 42'$	$88^\circ 51'$	$66^\circ 43'$	$52^\circ 45'$
0.4	$-82^\circ 53'$	$75^\circ 58'$	$61^\circ 44'$	$51^\circ 41'$	$36^\circ 20'$	$27^\circ 49'$
0.6	$71^\circ 34'$	$54^\circ 11'$	$43^\circ 11'$	$35^\circ 41'$	$24^\circ 40'$	$18^\circ 45'$
0.8	$55^\circ 30'$	$41^\circ 37'$	$32^\circ 55'$	$27^\circ 05'$	$18^\circ 36'$	$14^\circ 06'$
1.0	$45^\circ 00'$	$33^\circ 41'$	$26^\circ 34'$	$21^\circ 49'$	$14^\circ 56'$	$11^\circ 19'$
1.5	$30^\circ 21'$	$22^\circ 43'$	$17^\circ 51'$	$14^\circ 38'$	$9^\circ 59'$	$7^\circ 33'$
2.0	$22^\circ 50'$	$17^\circ 06'$	$13^\circ 26'$	$11^\circ 00'$	$7^\circ 30'$	$5^\circ 40'$
3.0	$15^\circ 16'$	$11^\circ 30'$	$8^\circ 36'$	$7^\circ 20'$	$5^\circ 00'$	$3^\circ 49'$
4.0	$11^\circ 27'$	$8^\circ 35'$	$6^\circ 44'$	$5^\circ 31'$	$3^\circ 45'$	$2^\circ 50'$
5.0	$9^\circ 10'$	$6^\circ 52'$	$5^\circ 24'$	$4^\circ 25'$	$3^\circ 00'$	$2^\circ 16'$
7.5	$6^\circ 07'$	$4^\circ 35'$	$3^\circ 36'$	$2^\circ 56'$	$2^\circ 00'$	$1^\circ 31'$
10.0	$4^\circ 35'$	$3^\circ 27'$	$2^\circ 42'$	$1^\circ 55'$	$1^\circ 30'$	$1^\circ 08'$

phase difference is only a few degrees and therefore, so far as useful in measurements, is practically negligible. In other words the reflected light, although elliptically polarized, approaches plane polarized light in character and the essential phenomena to be observed are intensity differences and rotation of the plane of vibration. This statement is valid for all substances of refractive index above 3.0 and for substances of still lower refractive index (1.5) provided the absorption index is either high or very low (less than 0.3). The

region for which slight changes in refractive index or absorption index produce the greatest difference in phase are for low refractive indices  $n < 1.5$  especially for  $n < 1$  and for high absorption indices. Substances, however, with such indices are rare; the conclusion is therefore generally valid that the phase difference between the two components of a birefracting and biabsorbing substance for ver-

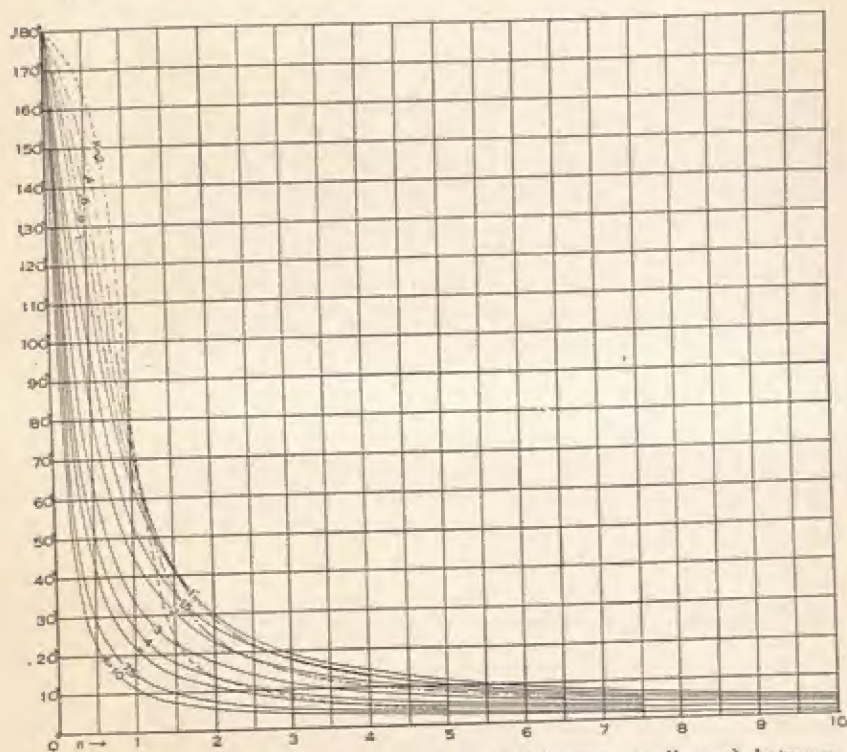


FIG. 6. In this figure is given the phase difference (ordinates) between one of the components of normally incident polarized light (azimuth  $\epsilon = 45^\circ$ ) and the same component after reflection from a birefracting, biabsorbing crystal plate of refractive index  $n$  (abscissæ) and absorption index  $k$  (curves).

tically incident light is not great and that the anisotropism finds expression chiefly in the intensity differences of the two components. This conclusion is important, since it enables the observer to apply the methods outlined above for non-absorbing media to the detection of anisotropism in opaque substances.



The amplitudes  $Rs$ ,  $Rp$  (equation 20, 24) are complex and of the form  $f + ig$ . In order to compound these two vibrations (vectors) and to ascertain the directions of the resultant elliptical vibration let (equation 21)

$$\begin{aligned}Rs &= r_1 e^{i(\tau - \Delta_1)}, \\Rp &= r_2 e^{i(\tau - \Delta_2)}.\end{aligned}\quad (39)$$

If  $\psi$  be the angle between the  $Rp$  axis and the major axis of the resultant ellipse of vibration, then we find by taking the real parts of (39), namely

$$\begin{aligned}Rs &= r_1 \cos(\tau - \Delta_1), \\ \text{and } Rp &= r_2 \cos(\tau - \Delta_2),\end{aligned}\quad (40)$$

and compounding them into the form

$$\begin{aligned}u_0 &= r_0 \cos(\tau - \Delta_0), \\ v_0 &= r_0 \sin(\tau - \Delta_0),\end{aligned}\quad (41)$$

which obtains for the components after the principal axes of the elliptical vibration, that

$$\tan 2\psi = \frac{2r_1 r_2}{r_1^2 - r_2^2} \cos(\Delta_1 - \Delta_2). \quad (42)$$

To effect this transformation the normal transformation equations

$$\begin{aligned}u_0 &= u \cos \psi + v \sin \psi, \\ v_0 &= -u \sin \psi + v \cos \psi,\end{aligned}\quad (43)$$

are used and the coefficients of  $\cos \tau$  and  $\sin \tau$  of equations (41) and (43) are equated.

If we put

$$\frac{r_2}{r_1} = \tan \theta, \quad (44)$$

equation (42) may be written

$$\tan 2\psi = \tan 2\theta \cos(\Delta_1 - \Delta_2). \quad (45)$$

The quantities on the right hand of this equation can be computed from equations (27), (29), (40) and (41), (44); but the expression thus obtained is too complicated to be readily interpreted. The fact that the phase difference for most opaque substances is, as

shown above, small and therefore the cosine of the angle  $(\Delta_2 - \Delta_1)$  not greatly different from unity indicates that  $\psi$  is only slightly smaller than  $\theta$  whose tangent is (equations (22) and (44))

$$\tan^2 \vartheta = \frac{r_2^2}{r_1^2} = \frac{[(n_2 - 1)^2 + n_2^2 \kappa_2^2][(n_1 + 1)^2 + n_1^2 \kappa_1^2]}{[(n_2 + 1)^2 + n_2^2 \kappa_2^2][(n_1 - 1)^2 + n_1^2 \kappa_1^2]}.$$

The right-hand side of this expression is identical with that obtained for the intensity ratio. Therefore, in general, the square of the tangent of the angle of rotation  $\theta$  is approximately equal to the intensity ratio. As this increases so also does the angular rotation of the plane of polarization.

The above equations and the methods based on these equations do not suffice for the determination of the optical constants  $n_1$ ,  $n_2$ ,  $\kappa_1$ ,  $\kappa_2$  of an opaque crystal examined only under vertical incidence. They do indicate, however, that for the detection of anisotropism the phase difference between the two components  $R_s$  and  $R_p$  is ordinarily not sufficiently large to be readily measured and that therefore the phase difference is of little value as a diagnostic feature. The other variable factor is the amplitude ratio. This gives rise to a difference in intensity of the components of the reflected wave. For certain cases in which the reflected waves are plane-polarized one of the components is more intense than the second and the excess in intensity in the one direction produces a certain amount of polarized light after reflection of the non-polarized, incident waves; this can be detected by methods similar to those which have long been in use for the detection and measurement of polarized light in the sky. Since for most substances the phase difference between the reflected components is not great, methods suitable for the detection of small angular rotations of the plane of polarization of incident plane-polarized light may also be used to detect anisotropism in opaque bodies. A brief description of the several methods which may serve for this purpose will now be given.

#### METHODS BASED ON INTENSITY CONTRAST.

These methods are widely used in the measurement of sky polarization and have proved to be of great usefulness in that connection. One of these methods has been applied by J. Koenigsberger to the detection of anisotropism in plates of opaque crystals.



*Koenigsberger's Method.*<sup>6</sup>—In a series of articles Koenigsberger suggested the use of a Savart plate<sup>7</sup> in conjunction with an analyzing nicol and a telescope for the detection of polarization in light

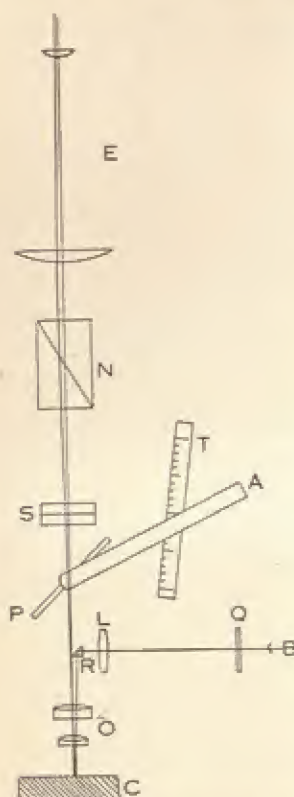


FIG. 7. Koenigsberger's apparatus for the detection and measurement of anisotropism in opaque substances.

reflected from a crystal surface, the incident light to be non-polarized and to impinge vertically on the plate. The arrangement proposed by Koenigsberger is illustrated in Fig. 7. The non-polarized light (monochromatic or white) enters the system along B, passes through a contrast plate Q consisting of a bi-plate of smoky quartz cut parallel to the axis and mounted so that the axis is at right angles in the adjacent halves; a lens L, for imaging the contrast plate in the image plane of the telescope E. The light passes through L to a small reflecting prism R, thence through the objective O to the crystal plate C where it is reflected back through O past R, through a plane-parallel, rotatable glass plate P of known refractive index ( $n=1.515$ ), through the Savart plate S and the nicol N into the telescope E.

The Savart plate consists of two plates of calcite or quartz cut at an angle with the optic axis sufficiently large ( $45^\circ$ ) that if examined in convergent polarized light the isochromatic curves of the interference figure cross the field as practically straight lines. The two plates are of equal thickness and are superimposed so that the horizontal projection of the axis in the one is at right

<sup>6</sup> *Centralblatt für Mineralogie, Geologie u. Paläontologie*, 1901, pp. 195-197; 1908, pp. 565-569, 597-605; 1909, pp. 245-250; 1910, pp. 712-713.

<sup>7</sup> Devised and first described by D. Brewster, *Edinburgh Transactions*, 9, 148, 1819; described later by Savart, *Pogg. Ann. d. Phys.*, 49, 292, 1840.

angles to that of the axis in the second. The relations are shown in Fig. 8. If the combination be observed between crossed nicols with the axes at  $45^\circ$  with the principal nicol planes, a series of parallel, vertical dark interference bands appears, if monochromatic light be used, in the field; if a white light source be used the bands, except one central band, are colored. These bands are similar in appearance to the bands in a quartz wedge or a Babinet compensator; but their mode of formation is different as they depend on very slightly convergent polarized light for their development while in the quartz wedge the change in thickness of the wedge introduces the required

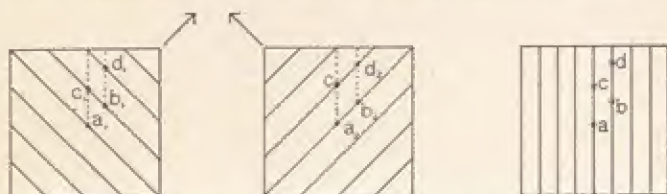


FIG. 8. Diagrams illustrating the principle on which the construction of the Savart plate is based.

path difference. From the mode of formation it is evident that if non-polarized light be used no such bands will appear, but that with a small percentage of polarized light there will be superimposed on the white field a series of colored bands the intensity of which increases with the amount of polarized light present. Under the best conditions of setting at the center of the light bands the maximum intensity is obtained, namely,  $\frac{1}{2}$  of total non-polarized light and  $\frac{1}{2}$  of total polarized light; whereas at the center of the dark central band only the non-polarized portion is transmitted. At intermediate points the non-polarized light and a part of the polarized component is transmitted. The field, therefore, alternates in intensity; the least amount of polarized light which can be detected depends obviously on the least perceptible increment in intensity which the eye is able to detect. As noted above Koenig and Brodhun's data place this difference limen at 1.6 to 2 percent. for favorable intensity of illumination. Pickering and others<sup>a</sup> estimate that in sky polarization about 1 per cent. of polarized light can be detected. Koenigsberger

<sup>a</sup> Report of U. S. Naval Observatory of Total Eclipse of July 29, 1878.



asserts that 0.3 per cent. difference can be detected, but a series of experiments by the writer using a rotating, optically plane-parallel plate and different sources and intensities of illumination indicate that the figures of Koenig and Brodhun are more nearly correct and that Koenigsberger's statement of the precision attainable is about 5 times too great. The difference between different settings, especially for large intensity differences, is of course considerably less than the least perceptible increment but this difference may not be considered to be the least perceptible increment itself.

In order to render more readily visible the Savart bands and the point of exact compensation Koenigsberger employs a contrast bi-plate of smoky quartz which introduces a difference in intensity between the components (result of pleochroitic absorption) and thus produces a shift of the lines in the halves of the field; these lines are then shifted by the changes in intensity resulting on reflection from an anisotropic crystal plate.

In the practical application of this method it is essential that the plate to be examined be well polished and normal to the axis of the microscope; that the reflecting prism be not too large; that the rotating glass plate *P* be mounted with its axis at  $45^\circ$  with the upper nicol plane; that the Savart plate be accurately constructed and be normal to the microscope axis; that the telescope be accurately focussed on infinity (in order that convergent light of only very small angular aperture pass through the Savart plate). To measure the degree of anisotropism the glass plate *P* is rotated until the effect of the crystal plate is exactly compensated and the Savart bands disappear or are separated by exactly half a band if the contrast band be used.

The effect of the tilted plate in compensating intensities normal and parallel with the plane of symmetry can be found from equations 15 simplified for the case of an isotropic body. Thus if *D* be the amplitude of the transmitted plane-polarized wave and  $\delta$  its azimuth, we find

$$D \cos \delta = E \cos \epsilon \frac{\sin 2r \sin 2i}{\sin^2(i+r)} = E \cos \epsilon \cdot C_1,$$

$$D \sin \delta = E \sin \epsilon \frac{\sin 2r \sin 2i}{(\sin i \cos i + \sin r \cos r)^2} = E \sin \epsilon \cdot C_2.$$

The intensity contributed by the component of the wave  $D$  (azimuth  $\delta$ ) in the plane of incidence is accordingly

$$D^2 \cos^2 \delta \cdot \delta \epsilon = E^2 \cos^2 \epsilon \cdot C_1^2 d\epsilon.$$

The total intensity for the components of all waves  $D$  (non-polarized light) in the plane of incidence is

$$E^2 C_1^2 \int_0^{\pi/2} \cos^2 \epsilon \cdot d\epsilon.$$

Similarly the total intensity for the components of all waves  $D$  (non-polarized light) normal to the plane of incidence is

$$E^2 C_2^2 \int_0^{\pi/2} \sin^2 \epsilon \cdot d\epsilon.$$

The ratio of the two intensities is

$$\frac{I_p}{I_s} = \frac{C_1^2}{C_2^2} = \frac{(\sin i \cdot \cos r + \sin r \cdot \cos i)^4}{\sin^4 (i + r)} = \cos^4 (i - r). \quad (46)$$

The same expression can be derived more directly from equation (16) if we consider the waves to pass through the system in reverse direction which is permissible. A series of values computed by means of this equation is listed in Table 8 and shown by the curve of Fig. 9.

TABLE 8.

Let a plane-polarized light beam be incident at the angle  $i$  on a plane parallel glass plate of refractive index 1.515; let the plane of polarization include angle of  $45^\circ$  with the plane of incidence. The ratios of the intensities of the two components, parallel and normal to the plane of incidence, of the beams emerging from the plate under these conditions are given in this table.

$i$	$I_p/I_s = \cos^4 (i - r).$	$i$	$I_p/I_s = \cos^4 (i - r).$
$0^\circ$	1.0000	25	67.47
5	.9848	30	56.25
10	.9406	35	45.02
15	.8705	40	34.51
20	.7798	45	25.00

In this figure the curve drawn by Koenigsberger and furnished with his apparatus is reproduced as the dotted curve. (Refractive index



of glass plate  $= 1.515$ ). The two curves do not coincide; no satisfactory explanation for the discrepancy has yet been found.

Photometrically the gradation in intensity between the different Savart bands is less advantageous than the juxtaposition of two or a series of evenly illuminated fields, the one at minimum intensity the next at maximum intensity. This principle is used in measurements of sky polarization and can be readily applied to the present problem.

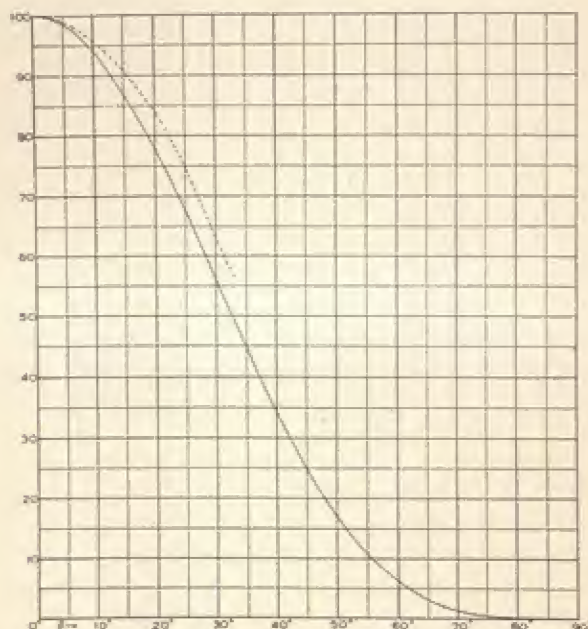


FIG. 9. Curve illustrating the percentage intensity ratio (ordinates) between the two components, normal and parallel to the plane of incidence, of light transmitted through a tilted glass plate for different angles of rotation (abscissae).

*New Method.*—For this method use is made of a cleavage plate of calcite of such thickness and an aperture of such width that the two fields from the two rays just touch (Fig. 10); better fields are obtained by use of a small Koenig-Martens portable photometer<sup>9</sup> (Fig. 11).

<sup>9</sup> *Verhandlungen d. deutsch. Physikal. Gesellschaft*, 1, 204-208, 1899; *Physikalische Zeitschrift*, 1, 299-303, 1900.

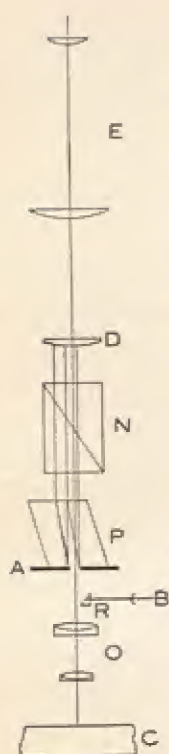


FIG. 10. New method for the detection and measurement of the degree of anisotropism of a crystal plate. In this method the cleavage plate of calcite serves to produce two adjacent fields whose planes of polarization are normal to each other. The intensity of the illumination of the two fields is made equal by rotation of the nicol *N*.

In Fig. 10 the non-polarized incident light is reflected by the prism *R* to the plate *C* whence it passes on reflection through the calcite plate aperture *A* to the nicol *N*, the weak lens *D* and the microscope eyepiece *E*. In the writer's microscope the upper nicol can be rotated and the angle of rotation read off to  $6'$  on the stage of the microscope. The function of the low-power lens *D* is to image the aperture *A* in the focal plane of the weak eye lens *E*.

In Fig. 11 the calcite plate is replaced by the Koenig-Martens arrangement of aperture *A*, field lens *D* (to render rays from aperture *A* to Wollaston prism *W* parallel), and the twin prism *F*. This gives a better photometric field than the calcite cleavage plate. In both methods artificial light, non-polarized, and either monochromatic or white is used and rendered diffuse either by the interposition of a ground glass or opal glass plate. The fields should be equally illuminated and no junction line between them should be visible. In case

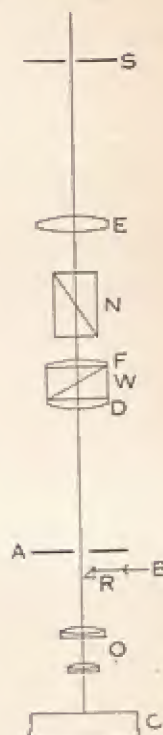


FIG. 11. In this method the Koenig-Martens arrangement of wollaston prism and twin glass prism is substituted for the calcite cleavage plate of Fig. 10. The intensity of the illumination of the two adjacent fields is rendered equal by rotation of the nicol *N*.

polarized light be present the intensity of illumination of the two fields is different; but it can be made equal by rotating the Nicol *N*



through an angle  $\alpha$ ; in this case the observed intensity from the one field of intensity  $I$ , is  $I \cos^2 (45^\circ - \alpha)$ ; that of the second,  $I_2$ , is  $I \cos^2 (45^\circ + \alpha)$ . Since the observed intensities are equal we have

$$\frac{I_2}{I_1} = \frac{\cos^2 (45^\circ + \alpha)}{\cos^2 (45^\circ - \alpha)} = \tan^2 (45^\circ - \alpha). \quad (47)$$

A series of values computed by means of this equation is listed in Table 9. For practical purposes a large-scale curve plotted on millimeter cross section paper is useful for ascertaining intermediate values.

TABLE 9.

In this table are listed the relative intensities of the sources of illumination of the two fields of a calcite rhomb or a Koenig-Martens photometer for different settings  $\alpha$  of the nicol  $N$  at which equal field intensities are obtained.

$\alpha$	$\tan^2 (45-\alpha)$	$\alpha$	$\tan^2 (45-\alpha)$	$\alpha$	$\tan^2 (45-\alpha)$
$0^\circ$	1.0000	$7^\circ$	.6104	$18^\circ$	.2596
1	.9326	8	.5678	20	.2174
2	.8696	9	.5279	25	.1325
3	.8107	10	.4903	30	.0718
4	.7557	12	.4217	35	.0311
5	.7041	14	.3610	40	.0077
6	.6558	16	.3073	45	.0000

Of the two devices the Koenig-Martens photometer is the better because it gives a better photometric field and is an attachment complete in itself which may be used on any microscope in place of the eyepiece. The only additional accessory required is the reflecting prism or mirror with which every metallographic microscope is equipped.

These methods are superior to the Koenigsberger method, not only because of increased sensitiveness, but also because the particular plate under investigation can be viewed directly (at high or low magnifications) and the test made directly on the plate in full view. In the Koenigsberger method the Savart bands are not readily distinguished unless the plate is brought out of sharp focus and even then the irregularities of the image tend to render indistinct and uncertain the faint Savart bands.

METHODS BASED ON THE DETECTION OF A ROTATION OF THE PLANE OF POLARIZATION  
(POSITION OF EXTINCTION).

These methods have been long in use by petrologists and the principles underlying the construction of the different devices need not be repeated here.<sup>10</sup>

*Koenigsberger's Method.*<sup>11</sup>—In this method Koenigsberger adopted the arrangement shown in Fig. 12. The incident light passes first through the polarization prism (vibration plane horizontal or vertical) *P*, and the total reflecting prism *R* to the crystal plate whence it travels through the Biot quartz plate *A* (cut normal to the axis and of such thickness, 3.75 mm., that it gives the sensitive tint between crossed nicols), the eyepiece *E*, the cap nicol *N* to the eye of the observer. The rotation of the plane of polarization on reflection is detected by the change in interference hue on rotating the crystal plate. Koenigsberger emphasizes the fact that this method is not so sensitive as his first method and is only qualitative in nature.

*Hanemann's Method.*—In 1913 Hanemann<sup>12</sup> improved Koenigsberger's method by substituting a Soleil-Biot plate (two adjacent Biot quartz plates, 3.75 mm. thick, cut normal to the axis, the one of right-handed, the second of left-handed quartz) for the single Biot plate. This arrangement introduces the feature of color con-



FIG. 12. Diagram showing general arrangement for the detection of the rotation of the plane of polarization of normally incident plane-polarized light waves on reflection from a birefracting and bi-absorbing plate.

<sup>10</sup> These are treated at length in "The Methods of Petrographic Microscopic Research," Carnegie Institution of Washington Publication 158, pp. 115-148, 1911.

<sup>11</sup> *Centralblatt für Mineralogie*, etc., 1909, 245-250; 1910, 712-713; *Metal-lurgie* 4, 605-608, 1909.

<sup>12</sup> K. Endell and H. Hanemann, *Stahl und Eisen*, 1913, p. 40; *Zeitschrift für anorganische Chemie*, 83, 267-274; 88, 265-268, 1914.



trast in adjacent fields and is accordingly more sensitive than the Koenigsberger method.

The Bertrand eyepiece which is in common use by petrologists would serve the purpose as well as, and possibly better than, the Soleil-Biot plate employed by Hanemann.

*New Method.*—The methods of Koenigsberger and of Hanemann are based on changes in color (sensitive tint) on rotation of an anisotropic plate. In the case of strongly colored substances, especially yellow minerals, the natural color dominates the field so effectively that the sensitive tint is no longer present as such and the slight changes in hue on rotation of the stage are only with difficulty detected and may be overlooked. The sensitiveness of these methods varies therefore with the color of the substance under examination. It is also difficult to obtain a uniformly colored field under average conditions of illumination, especially near the junction lines in the field.

In measurements of this nature in which the effective conditions vary within wide limits, whereas the sensitiveness of the eye (threshold vision) is more or less fixed it is essential for the best results that the sensitiveness of the device employed for the measurement be variable so that the most sensitive conditions of observation can be obtained. It is on this principle of variable sensibility that the writer's bi-quartz-wedge-plate<sup>13</sup> was constructed.

On substituting the bi-quartz-wedge-plate for the Biot plate of Koenigsberger or the Biot-Soleil plate of Hanemann the most sensitive arrangement for the detection of anisotropism in opaque substances is obtained. The method is exceedingly simple and requires no apparatus in addition to that furnished with a research model petrographic microscope. The observations are made either in white or in monochromatic light. The degree of anisotropism is indicated by the amount of angular rotation of the cap nicol required to produce equal intensity of illumination in the adjacent halves of the bi-quartz-wedge-plate.

Other devices, such as the half-shade Lippich prism, may be substituted for any one of the rotating quartz plates and wedges but

<sup>13</sup> *Am. Jour. Sci.* (4), 26, 377-378, 1908; Carnegie Institution of Washington, Publication 158, 140-142, 1911.

since the apparatus is more complicated and the attainable accuracy is not increased, such devices are not recommended for practical work.

*Effect of Reflecting Prism or Plate on the Character of Light.*—

An extended series of experiments with different kinds of reflectors, total reflecting prisms, silver surfaces, silvered glass mirrors with central aperture or a small disk mirror in center of field, or an Abbe reflecting cube, was carried out to ascertain if possible which type is the best for such work, especially for use with the second group of methods. The general equations state that in case the azimuth of the plane of polarization of the incident wave is zero or  $90^\circ$ , the reflected beam is still plane polarized; practical experience with such reflectors states, however, that the reflected beam always shows traces of elliptical polarization even when the plane of polarization is horizontal or vertical. This is no doubt due in the case of reflecting glass surfaces to internal reflections; with a blank metal reflecting surface, such as the fresh silver side of a silvered mirror, it may result from strains in the outer film. Be the cause what it may, in no experiment was the elliptic polarization entirely removed, and the accuracy of the settings was correspondingly diminished. Experience with the different types of reflectors did not demonstrate marked superiority of any one particular type. It is, of course, essential that the plane of polarization of the incident beam be strictly horizontal or vertical in order to reduce to a minimum the amount of elliptic polarization present.

MEASUREMENT OF PHASE DIFFERENCES IN REFLECTED WAVES.

The curves of Fig. 6 prove that in general the phase difference between the components of the reflected waves normal and parallel to the plane of incidence is of a low order of magnitude, so low in fact that it may in general be neglected. The actual measurement of the phase difference is best accomplished by the standard method with a Babinet compensator. In view of the slight differences to be observed, however, this method is not to be recommended for practical diagnosis.



*The Effect of Thin Surface Films on the Character of the Reflected Light.*—Drude<sup>14</sup> was the first to emphasize the importance of thin surface films in affecting the polarization relations of reflected and of transmitted light waves. In the case of opaque substances (ores and metals) the surface film effects may be serious and cause an isotropic mineral to show evident phenomena of anisotropism. Thus a sheet of copper or other isotropic metal shows distinct anisotropic effects. The rolled surface of the metal is striated and part of the polarization effects may be of the nature of grating polarization effects or may result from reflection at oblique surfaces. Many ground surfaces of isotropic pyrite are decidedly anisotropic. In certain cases this is probably due, as Koenigsberger suggested<sup>15</sup> to grinding striae; but in other pyrite sections the anisotropism persists in spite of care taken to eliminate grinding striae. This may be the result of surface film effects or of strain birefringence in the pyrite. Its presence in random sections, even carefully ground, serves as a danger-signal, warning the observer against the drawing of too positive conclusions from a single section. As a general rule pyrite sections are isotropic and the conclusion is warranted that it is isometric, as crystallographic measurements prove it to be. The statement of Koenigsberger that surface films affect only the phase difference and not the amplitudes of the reflected beams is borne out neither by theory nor by practical experience. In general, however, it may be stated that surface film effects are not so pronounced as to affect seriously the validity of the determinations.

*The Use of Refractive Liquids.*—In case the medium surrounding the crystal be not air but a refractive liquid the refractive indices appearing in the above equations have to be reduced in the ratio of the reciprocal of the refractive index of the liquid; thus if  $n_0$  be the refractive index of the liquid,  $n_1$ ,  $n_2$  of the crystal plate must be replaced by  $n_1/n_0$ ,  $n_2/n_0$ . With each different refractive liquid employed both the intensity ratio of the reflected components and the angular rotation of the plane of polarization are changed. Theo-

<sup>14</sup> *Ann. d. Physik*, 43, p. 146, 1891; *Lehrbuch d. Optik*, 1906, pp. 272-280; Winkelmann's *Handbuch d. Physik*, Vol. 6, pp. 1278-1316, 1906.

<sup>15</sup> *Centralblatt für Miner., Geol. u. Paläontol.*, 1908, p. 597.

retically it is thus possible by measurements in different immersion liquids to determine the refractive indices  $n_1$ ,  $n_2$ , and also the absorption indices  $\kappa_1$ ,  $\kappa_2$  even with normally incident light; but practically this method is of little value because the results are encumbered with a large probable error due chiefly to the relative insensitiveness of the eye to slight changes in the observed phenomena.

In a transparent, birefracting substance the maximum effect is obtained by the use of a liquid of refractive index equal either to  $n_1$  or to  $n_2$ . The intensity of one of the reflected components is then zero; the intensity of the second component for  $n_0 = n_1$  is

$$\frac{I_{rp}}{I_r} = \left( \frac{n_2 - n_1}{n_2 + n_1} \right)^2,$$

which is a very small quantity for weakly birefracting substances; and even for strong birefringence such as that of calcite it amounts only to one half of one per cent. With intense illumination, however, relatively weak birefringence can be detected by the use of proper refractive liquids. Since clear refracting liquids of index above 2.2 are not available, it is not possible to obtain the most sensitive conditions of observation with minerals of very high refractive index, such as hematite and selenium. But with most minerals conditions of observation can be improved somewhat by the use of immersion liquids of proper refractive index. In practical work, however, it is doubtful if the improvement thereby gained is worth the bother.

#### SUMMARY.

In the foregoing pages the attempt has been made to present in connected form the electromagnetic theory of the reflection of light by absorbing media and especially that part of the theory which treats of the reflection phenomena resulting from vertically incident light waves under the conditions usually encountered in the use of the reflecting or metallographic microscope; this outline of the theory is given in order to indicate and also to emphasize the fundamental principles on which all methods involving the application of polarized light to the study of opaque substances are necessarily based; thus the possibilities and the limitations as well of



such methods are ascertained. It is shown in the general case that vertically incident, plane-polarized light waves become on reflection elliptically polarized (as a result of a difference in phase between the components parallel and normal to the plane of incidence); that the amplitude of the component of the light vector in the plane of incidence is different from that normal to the plane of incidence.

In special cases where crystallographic symmetry relations prescribe the positions of the principal axes of refringence and of absorption, as in isotropic, uniaxial, and the principal planes of orthorhombic crystals, the above relations are simplified to the extent that the refracted waves are plane-polarized and not elliptically polarized as in the general case; as a result, normally incident, plane-polarized light waves whose vibration directions are either parallel or normal to the plane of symmetry are reflected as plane-polarized waves; but the intensity of the two reflected waves is different because of the difference in the refractive and absorption indices parallel and normal to the plane of symmetry. Therefore normally incident, non-polarized light contains after reflection a certain amount of plane-polarized light and this amount increases with the strength of the birefringence and of the biabsorption in the crystal plate.

The presence of plane-polarized light in essentially non-polarized light can be detected by any one of the well-known physical methods, such as are commonly used in determinations of sky polarization. Of these methods Koenigsberger adopted the Savart plate with rotating glass compensator; a second method is suggested above which employs either a single calcite cleavage plate with proper aperture (after the manner of the Haidinger lens or the Pickering photometer) or a small portable Koenig-Martens photometer. This method is superior to the first method in two respects: it is simpler in adjustment and in manipulation; it is based on a photometrically better principle, namely contrast of two or a series of illuminated fields, the first at minimum intensity, the adjacent field at maximum intensity with a sharp line of demarcation which disappears when the intensity of illumination in the adjacent fields is the same. The attainable accuracy depends on the least perceptible difference in intensity of illumination which the eye can detect; this is about 1.5 to 2 per cent. under ordinary conditions of illumination. An opaque

crystal, therefore, of such weak birefringence or weak biabsorption such that the difference in intensity between the reflected components is less than 1.5 per cent. appears isotropic. In transmitted light differences in birefringence of only 0.02 per cent. of the refractive index are readily detectible; therefore the methods based on differences in intensity of the reflected components of vertically incident light are 50 or more times less sensitive in the detection of anisotropism than the methods based on the phenomena of plane-polarized, transmitted light waves.

In case the vertically incident light be plane-polarized, the difference in amplitude of the reflected components normal or parallel to the plane of symmetry causes a rotation of the plane of polarization and this can be detected and measured by any one of a number of devices in common use by petrologists. Of these Koenigsberger adopted a Biot sensitive tint plate and used it in a qualitative way to detect anisotropism. Hanemann improved Koenigsberger's method by adopting the Biot-Soleil sensitive tint bi-plate and obtained thereby a color contrast in two adjacent fields. The ordinary Bertrand eyepiece which is in common use by petrologists is suggested above as a still further and equally simple method for detecting anisotropism.

A still more sensitive and better method is, however, to use the writer's bi-quartz-wedge-plate in which the sensibility is variable and can be adjusted to meet the conditions of illumination and thus to produce the most favorable conditions for extreme sensitiveness and consequent accuracy of results of measurement. This method is simple and is the most sensitive at present available for detecting and measuring anisotropism in opaque substances. The degree of anisotropism is indicated by the amount of angular rotation on reflection of the plane of polarization of the vertically incident light waves. The accuracy of these methods depends on the threshold limit of vision (least intensity of light which the eye can detect); this is different from the least perceptible difference in intensity of illumination of two adjacent fields on which the sensitiveness of the first group of methods depends.

The sensitiveness of the second group of methods can be increased by increasing the intensity of the light source and also by



introducing some contrast device such as the bi-quartz-wedge-plate, or the Lippich biprism. In general it may be stated that for practical purposes the methods of the second group are simpler in manipulation than those of the first and more sensitive and therefore better. A disturbing factor is the introduction of a small amount of elliptically polarized light by the reflecting prism or plate. The phase differences between the two components of the reflected waves are in general small and do not seriously affect measurements by the methods outlined above which are based on the amplitude differences between the two components. The phase differences may be measured by one of several devices of which the Babinet compensator is the best and most widely used; but for the detection and measurement of anisotropism, methods, which are based on phase differences between the components after reflection of vertically incident plane-polarized light, are not in most cases of practical value.

The use of immersion liquids and a monochromatic light source is suggested for obtaining the greatest differences in intensity between the reflected components and thereby increasing the sensitiveness of the methods for detecting anisotropism.

The above equations show that it is in general not possible to measure both the refractive indices and the absorption indices of an opaque body by means of the phenomena resulting on the reflection of vertically incident light waves; but it is possible in special cases to determine the degree of anisotropism and also the positions of the polarization directions in a given crystal plate. These data taken in conjunction with crystallographic data enable the observer, just as do birefringence and extinction angles in transparent crystals, to draw conclusions regarding the crystal system of the substance under investigation. But in opaque substances the precision attainable is relatively slight and the phenomena which can be observed are relatively few and restricted in scope. As a result one cannot expect from the application of polarized light to such substances the harvest of optical data which have been gathered from transparent crystals. For opaque bodies the possibilities are few, the limitations are great, and recourse must be had in practical diagnosis to other methods of determination such as behavior of the substance toward abrasives

and solvents, color, density, hardness, etc., in addition to the determination of the degree of anisotropism.

In this paper the properties of a number of opaque substances such as ores and metals, determined by the several methods described above, are not included; such lists would add materially to its length and are not germane to its purpose.

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# ON THE LUCIOPIMELODINÆ, A NEW SUBFAMILY OF THE SOUTH AMERICAN SILURIDÆ.<sup>1</sup>

(PLATES II AND III.)

By CHAS. S. DRIVER.

(Communicated by Prof. Carl H. Eigenmann. Read October 3, 1919.)

In the Nematognathi or catfishes and their relatives the anterior vertebræ are coalesced and form with the auditory ossicles the so-called Weberian apparatus. This structure has been studied by various authors notably Sagemehl,<sup>2</sup> R. Ramsay Wright<sup>3</sup> and Bridges and Haddon.<sup>4</sup> A brief summary is also given by Boulenger in his "Fishes of the Congo" and in other papers on systematic ichthyology by Regan, Eigenmann, et al. Usually the centra of the first three vertebræ are coalesced into one piece without evident sutures. The centra of the fourth, fifth and sixth vertebræ are frequently coalesced with the anterior three, but the sutures between the third and fourth as well as between the fourth and fifth are frequently quite evident, especially in the young.

The coalesced first to third vertebræ are without lateral processes. The fourth and fifth have various processes.

As in all other members of the Nematognathi, the centra of the anterior vertebræ of the species of the Pimelodinæ, a subfamily of South American catfishes, are coalesced. The lateral processes of the fourth, fifth and sometimes the sixth vertebræ are expanded, sometimes largely separated from each other, more frequently joined to each other to form an osseous shield or roof over the anterior part of the abdominal cavity.

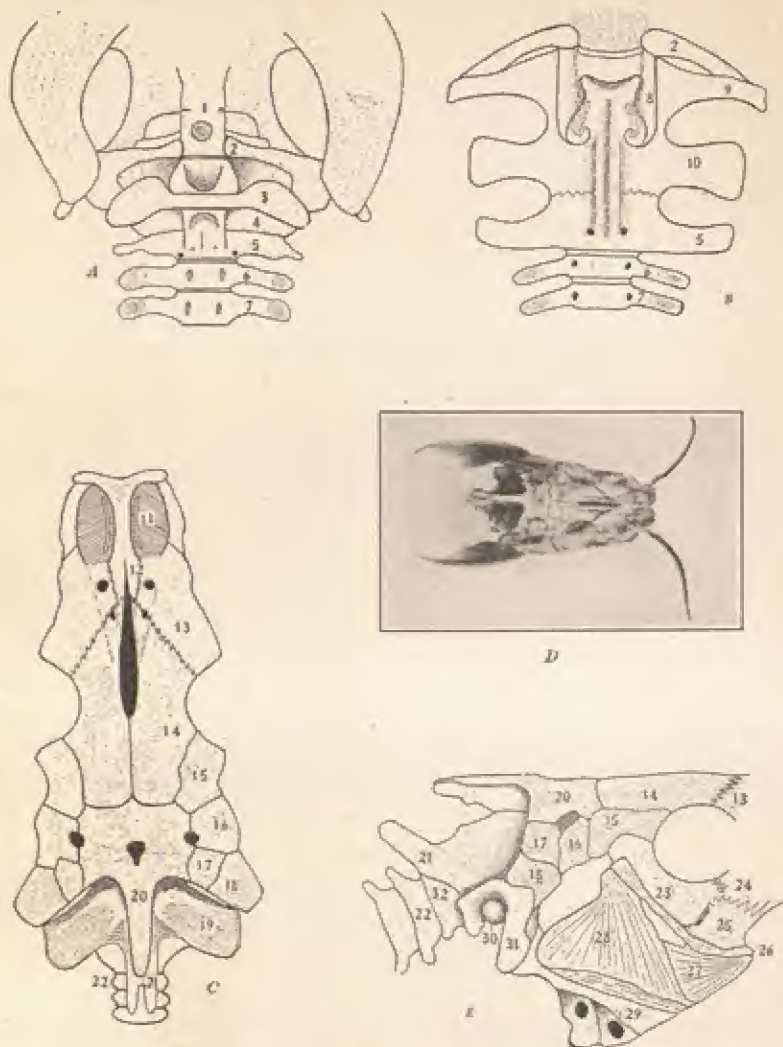
In *Rhamdia* of the *Pimelodinæ* there are three processes distinct

<sup>1</sup> Contribution from the Zoölogical Laboratory of Indiana University, No. 166.

<sup>2</sup> *Morpholog. Jahrb.*, Bd. X.

<sup>3</sup> *Trans. Roy. Soc. Canada*, 1885.

<sup>4</sup> *Phil. Trans. Roy. Soc.*, B, 1893.



*A*, ventral view of the anterior vertebrae of *Perugia xanthus*; *B*, ventral view of anterior vertebrae of *Rhamdia cinerascens*; *C* and *D*, dorsal views of skull of *Perugia xanthus*; *E*, lateral view of *Perugia xanthus*.

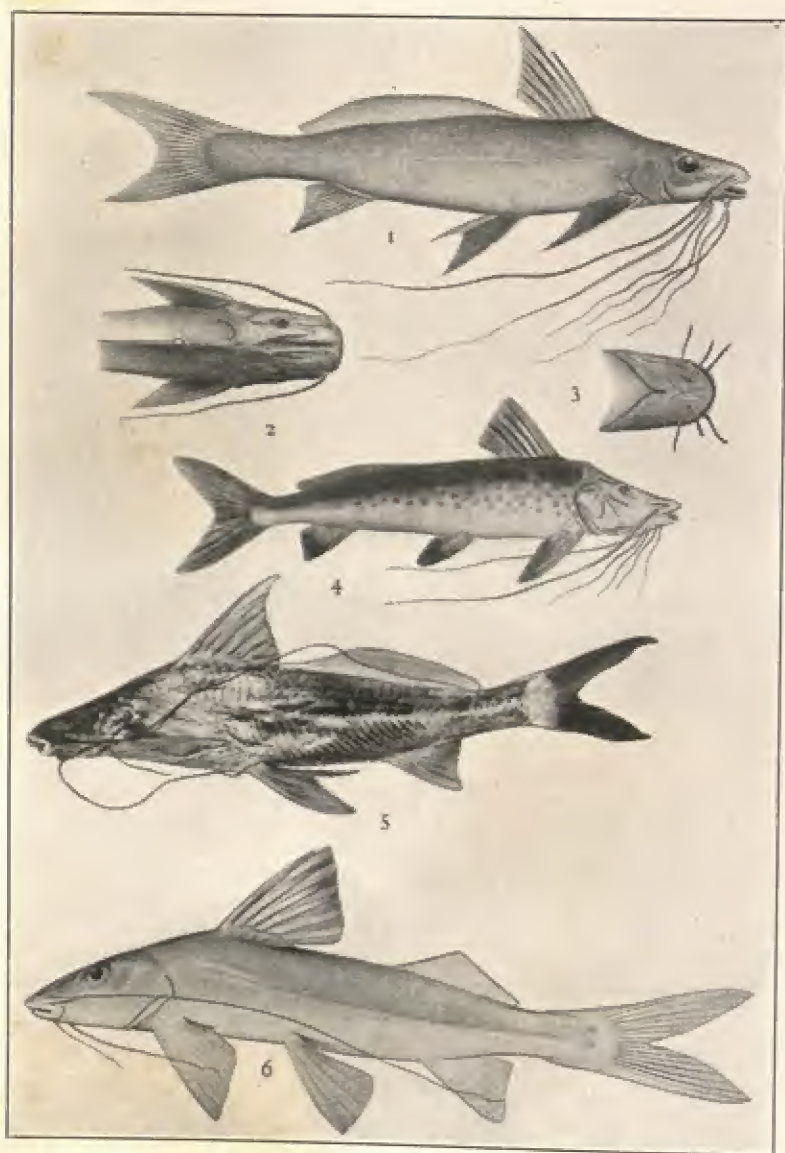
1, Basioccipital; 2, inferior process of post-temporal; 3, ventral view of air bladder capsule; 4, transverse process of fourth vertebra; 5, transverse process of fifth vertebra; 6, transverse process of sixth vertebra; 7, transverse process of seventh vertebra; 8, concentric process of tripus; 9, anterior process of fourth vertebra; 10, posterior process of fourth vertebra; 11, nasal; 12, ethmoid; 13, lateral; 14, frontal; 15, sphenotic; 16, pterotic; 17, epiotic; 18, supraclavical; 19, dorsal view of air-bladder capsule; 20, supraoccipital; 21, neural spine of fourth vertebra; 22, sixth vertebra; 23, hyomandibular; 24, metapterygoid; 25, quadrate; 26, preopercle; 27, interopercle; 28, opercle; 29, clavicle; 30, end of air-bladder; 31, lateral view of air-bladder capsule; 32, fifth vertebra.











- 1-3. *Perugia agassizii* (Steindachner). After Steindachner.
4. *Luciopimelodus pati* (Valenciennes). After Valenciennes.
5. *Perugia xanthus* (Eigenmann). Photograph by Eigenmann.
6. *Megalonema platycephalum* Eigenmann. After Eigenmann.

from each other for more than their distal halves (Plate II, *B*, 9, 10, 5). The first one articulates distally with the clavicle and process of the post-temporal, the second and third are free at the ends. The first and second (9 and 10) belong to the fourth vertebra,<sup>5</sup> the third process belonging to the fifth vertebra. In *Pseudoplatystoma fasciatum* there are four expanded transverse processes, all of them separated from each other toward their distal ends. In small specimens of this species the interlocking sutures of the centra of the coalesced vertebræ are quite distinct. In this species it is quite evident that the first and second processes belong to the second distinguishable vertebra, in reality to the fourth. The fourth process belongs to a supernumerary modified vertebra, the sixth, one usually normal in other species. Its processes bear ribs. In *Pimelodus clarias* the lateral processes are united to form a solid plate without even marginal notches to indicate the boundaries between successive processes.

In the genera *Pimelodina*, *Pseudopimelodus*, *Rhamdia*, *Pimelodus*, etc., of the Pimelodinæ the air-bladder<sup>6</sup> is well developed and lies free in the abdominal cavity. It is simple and more or less oblong in shape and extends posteriorly to the eighth or tenth vertebra.

In *Sorubim* (Fig. 1, *A*) and *Hemisorubim* the air-bladder is drawn out more than in any of the other genera, and extends back past the tenth vertebra. It is larger proportionally than in any of the other genera. In *Pseudoplatystoma* and *Brachyplatystoma* it is very much as in *Sorubim* and *Hemisorubim* but slightly shorter, extending only past the ninth vertebra.

In *Rhamdia* (Fig. 1, *B*), *Pimelodella* and *Pimelodus* (Fig. 1, *C*) the air-bladder is very different from that found in *Sorubim*, *Hemisorubim*, *Pseudoplatystoma* and *Brachyplatystoma*. In these genera it is wider than long. The width averaging from one to three mm.

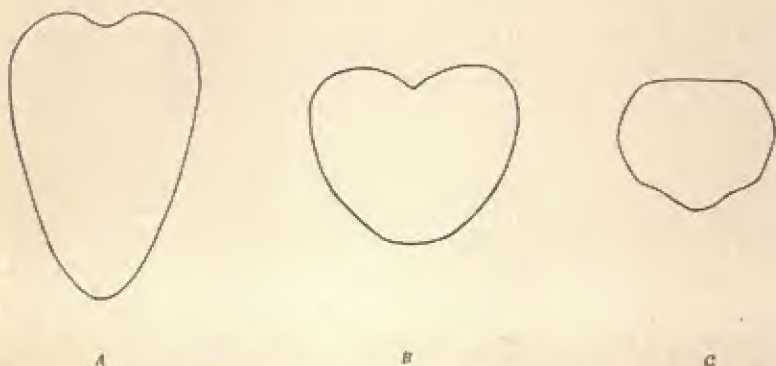
<sup>5</sup> Bridges and Haddon, *Phil. Trans.*, Vol. B, 1893.

<sup>6</sup> The air-bladder of one specimen of *Ageneiosus caucanus* has been examined to determine its relation to the Pimelodinæ, and to the genera *Megalonema* and *Luciopimelodus*. This specimen was 280 mm. long and its air-bladder was 23 mm. long and 23 mm. wide. It tapers at the posterior end, causing it to be heart-shaped. It lies free in the abdominal cavity and is not enclosed in a bony capsule. It thus resembles the condition found in the Pimelodinæ.



in excess of the length. In *Rhamdia* it extends to the ninth vertebra while in *Pimelodella* and *Pimelodus* it extends only to the eighth.

As stated, the lateral processes of the first five vertebrae in the Pimelodinæ are coalesced and form a more or less smooth roof beneath which the air-bladder lies. In *Rhamdia* (Plate II, Fig. B) the transverse processes are quite distinct, and are separated from each other; the coalescing is more complete in *Sorubium*, *Hemisorubim*, *Pimelodella* and reaches the climax in *Pimelodus*.



TEXT-FIG. 1. A, Air-bladder of *Sorubium lima*; B, Air-bladder of *Rhamdia cinarens*; C, Air-bladder of *Pimelodus clarias*. Outlines as seen from below.

The air-bladder of *Pimelodus* is small. The coalescing of the vertebrae is more complete in this genus than in others. The outer edge of the shield formed by the coalesced process has a tendency to become arched antero-posteriorly.

The air-bladder in all these genera comes in close contact with the skin which serves as a tympanic membrane. This can be seen especially well in young specimens.

*Perugia* (Plate II, A, C, D, E), which had hitherto been placed in the Pimelodinæ, has the air-bladder very much reduced in size, constricted longitudinally with one lobe on each side of the centra of the coalesced vertebrae. Each lobe is surrounded by a partial capsule, made up of the coalesced vertebrae above and behind, the scapula and the process connecting the scapula with the basioccipital in front. The floor of the capsule is membranous.

The two lobes of the air-bladder are very small. In a fish 200 mm. long they are 2.5 mm. in diameter and the distance between the outer margins of the two capsules measures 12 mm. They are pear-shaped, tapering to a small canal connecting the two capsules.

*Luciopimelodus* and *Megalonema* are certainly closely related to *Perugia*. This becomes quite evident when we examine the air-bladder and the anterior vertebræ associated with it. An examination of these structures also demonstrates that *Luciopimelodus* and *Megalonema* are not related to the *Pimelodina* with which they have been associated.

The air-bladders in these two genera are not in direct contact with the skin. They extend outward to near the skin, being separated from it by a thin layer of fat.

As in the structure of the air-bladder and the Weberian apparatus *Perugia*, *Luciopimelodus* and *Megalonema* differ greatly from all the genera of the *Pimelodina*, they may well be separated into a new subfamily, the *Luciopimelodina*.



TEXT-FIG. 2. *Megalonema platyodon* Günther. Photograph by Sr. Valette, Jefe de la Oficina Fomento de Pesca. Buenos Aires.

In Cuvier and Valenciennes, "Hist. Nat. Poissons," XV, 1840, p. 176, Valenciennes described a new species which he called *Pimelodus pati* basing his description on a specimen 30 inches long collected by d'Orbigny, a very small specimen which he received from the museum at Lisbon, and on a drawing in the MS. of Father Feuillee, in Hugard's library. Later in d'Orbigny's "Voyage dans l'Amerique Meridionale," V, 2<sup>e</sup> Partie; Poissons, 1847, p. 7, plate I., Fig. 7-9, Valenciennes figured the species.



D'Orbigny reported that the species is taken in the Paraná from latitude 26 degrees South to Buenos Aires. He reported it to be a permanent resident at Corrientes, but at Buenos Aires it is migratory, arriving in September and departing in March.

Günther in his Catalogue also placed it in the old genus *Pimelodus* which includes a number of different generic types. In a short article on the Fish-fauna of Rio de la Plata,<sup>7</sup> Günther briefly describes *Pimelodus platanus*. This species is without spots and it is quite possible that it was included in the species *pati* concerning which Valenciennes says (p. 178):

M. d'Orbigny nous dit que les taches varient à l'infini, et disparaissent quelquefois entièrement.

Eigenmann and Eigenmann<sup>8</sup> created the genus *Luciopimelodus* for *pati* and *platanus* placing the genus in the Pimelodinæ. They distinguished the genus by the flexible, non-spinous first dorsal and first pectoral rays, the elongate, spatulate, depressed head, the narrow, short occipital process, and the fontanel confined to the frontal portion of the head.

Steindacher<sup>9</sup> described *Pirinampus agassizii*. The relationship of this species with *pati* was not recognized by Steindachner or Eigenmann and Eigenmann, the latter placing it in a hypothetical distinct but unnamed genus numbered XXII in their monograph on the Nematognathi. This was later placed in a new genus, *Perugia*, by Eigenmann and Norris. Steindachner described this species as having a pungent dorsal spine, but Fisher<sup>10</sup> shows that in a specimen in the Carnegie Museum (No. 7251) there is evidence that the pungency is due to the fact that the tip of the first dorsal ray is broken off.

In his monograph on the Freshwater Fishes of British Guiana<sup>11</sup> Eigenmann describes the new genus and species *Megalonema platycephalum* from the lower Potaro River of British Guiana. The genus *Megalonema* differs from *Luciopimelodus* in the shape of the

<sup>7</sup> *Ann. and Mag. Nat. Hist.*, Vol. VI., July, 1880, p. 10.

<sup>8</sup> *Proc. Calif. Acad. Sci.* (2), I., 1888, p. 122, and *Occasional Papers Calif. Acad. Sci.*, I., 1890, p. 106.

<sup>9</sup> *S. B. Ak. Wien.*, LXXIV, 1876, *Ichthyol. Beitr.*, IV, Pl. 12.

<sup>10</sup> *Ann. Carnegie Mus.*, XI, 1917, p. 407.

<sup>11</sup> *Mem. Carnegie Mus.*, V, 1912, p. 150.

band of premaxillary teeth. The band is rounded at the outer end instead of prolonged into a sharp angle as in *pati*.

Still later Eigenmann<sup>12</sup> described *Megalonema xanthum* from the upper Magdalena River of Columbia.<sup>13</sup>

# KEY TO THE GENERA AND SPECIES OF LUCIOPIMELODINÆ.

- a. Mouth terminal, the lower jaw pointed, its tip extending to the tip of the upper jaw; premaxillary band of teeth with a long, backward projecting angle; adipose fin beginning at tip of last dorsal ray, its length little more than three in the length; snout greatly depressed; depth of head three in its length; post-mental barbels extending past base of the anal, A. 12; eye 10 in head, 4.5 in snout, 2.33 in interorbital. (Based on a specimen 230 mm. to base of caudal.) (*Luciopimelodus*.) ..... *pati*.
- aa. Jaws subequal, premaxillary band of teeth without a backward projecting angle.
  - b. Space between adipose and base of last dorsal ray considerably greater than base of dorsal ..... (*Megalonema*.)
    - c. Head 4; depth 6; adipose 4 in length; dorsal I, 6; A. 12; eye 2.5 in snout, 5 in head ..... *platanum*.
    - cc. Head 3.66 in the length; depth 5.5; adipose 4 in the length; dorsal I, 6; A. 11; eye 2 in the snout, 5 in head ..... *platycephalum*.
    - ccc. Head 4; depth 5.33; A. 9; adipose 4.95 in the length; eye 4 in the head, .75 in the interorbital; snout depressed, width of head at the rictus 2 in the length of the head; maxillary barbel reaching middle or beyond tip of pectoral; teeth in a very narrow band; fontanel reaching base of occipital crest which is minute; the first dorsal ray slender, a little longer than the head. (Based on a specimen 38 mm. in length.) ..... *pauciradiatum*.
  - bb. Space between adipose and base of last dorsal ray much shorter than the base of the dorsal, post-mental barbel not far behind the mental ..... (*Perugia*.)
    - d. Lower jaw but a little shorter than the upper, premaxillary band of teeth terminal, partly exposed when mouth is closed; fontanel increasing in width backward to behind the eye; a small fontanel at the base of the occipital process; head 5 in the length; depth 6; dorsal I, 6; A. 11 ..... *agassizii*.
    - dd. Snout much projecting, the mouth inferior; the premaxillary band of teeth very narrow; maxillary barbel extending past base of anal; adipose 2.5 in the length; fontanel wider behind than in front, extending to the posterior edge of eye; small fontanel at the base of the occipital process; A. 11 ..... *xanthus*.

<sup>12</sup> *Ind. Univ. Studies*, No. 16, Dec., 1912, p. 16.

<sup>13</sup> The species of *Megalonema* described by Meek from the Tuyra River belong to the genus *Pimelodus*.



The species of *Luciopimelodina* have so far been recorded from the La Plata Basin, from the Rio Jauri at the headwaters of the River Paraguay to the mouth of the La Plata at Buenos Aires, from the Amazon between Calderon and Para, from the Essequibo Basin in Guiana and from the Magdalena Basin in transandean Colombia. Their distribution is very wide which may indicate that they have been established in South America since before the days of the formation of the eastern Andes of Colombia.

#### SYNONYMY AND BIBLIOGRAPHY.

##### LUCIOPIMELODUS PATI (Valenciennes).

*Pimelodus pati* Valenciennes, Voy. d'Orbigny, pl. 1, figs. 7-9, 1847; Cuv. & Val., Hist. Nat. Poiss., XV, 176, 1840 (Parana; La Plata; Corrientes; Buenos Ayres); Kner, *Sb. Ak. Wien*, XXVI, 1857, 416 (Forte de S. Joaquim, Rio Branco); Günther, *Cat. Fish. Brit. Mus.*, V, 128, 1846 (copied).

*Luciopimelodus pati* Eigenm. & Eigenm., *Proc. Calif. Acad.*, 2d Ser., Vol. 1, 122 (Buenos Ayres); Eigenmann, *Repts. Princeton Univ. Exped. Patagonia*, III, 1910, p. 383 (name only); Fisher, *Ann. Carnegie Mus.*, XI, 1917, p. 407 (Buenos Aires).

*Habitat*: Rio Plata; Rio Branco near British Guiana.

##### MEGALONEMA PLATANUM (Günther).

*Pimelodus platanus* Günther, *Ann. Nat. Hist.* (5), VI, 10, 1880 (Parana, Rio Plata).

*Luciopimelodus platanus* Eigenm. & Eigenm., *Occasional Papers Calif. Acad. Sci.*, I, p. 108, 1890; Eigenmann, *Repts. Princeton Univ. Exped. Patagonia*, III, 1910, p. 383 (name only); Fisher, *Ann. Carnegie Mus.*, XI, 1917, p. 408 (Rio Jauru, Asuncion).

*Habitat*: Rio Plata; Piracicaba; Paraguay Basin.

##### MEGALONEMA PLATYCEPHALUM (Eigenmann).

*Megalonema platycephalum* Eigenmann, *Repts. Princeton Univ. Exped. Patagonia*, III, 1910, p. 383 (name only); Eigenmann, *Mem. Carnegie Mus.*, V, 1912, p. 150, Pl. X, fig. 2.

*Habitat*: Essequibo Basin.

MEGALONEMA PAUCIRADIATUM Eigenmann, spec. nov.

15029, I. U. M., four, the largest the type, 28–38 mm. Villa Rica. Anisits.

Head 4; depth 5.33; A. 9; adipose 4.75 in the length; eye 4 in the head, .75 in the interorbital; maxillary barbel reaching middle or tip of dorsal, postmental a little beyond tip of pectoral; teeth in very narrow bands; snout depressed, width of head at the rictus 2 in the length; depth of head nearly two-thirds its length; fontanel reaching base of occipital crest which is minute, reaching only about one-sixth of the way to the dorsal fin; distance between snout and dorsal 2–2.66 in the length; first dorsal ray slender, a little longer than the head, extending beyond all the rest when depressed; ventrals and base of third dorsal ray about equidistant from snout; first pectoral ray slender, reaching the ventrals, the latter not to the anal; caudal peduncle 5 in the length.

Air-bladder transverse, about three times as wide as long.

Pale, without any conspicuous markings.

The type is a female with mature eggs nearly a millimeter in diameter. While the specimens at hand have probably not reached full size, the largest is sexually mature.

This species differs from *Megalonema platanum* and *Luciopimelodus pati* of the Plata basin in having but nine anal rays while they have twelve.

PERUGIA AGASSIZII (Steindachner).

*Pirinampus agassizii* Steindachner, *Sb. Ak. Wien*, LXXIV, 1876; *Ichthyol. Beitr.*, IV, 57, pl. 12 (Para); Vaillant, *Bull. Soc. Philom.*, series 7, IV, 153, 1880 (Calderon).

? *agassizii* Eigenm. & Eigenm., *Occasional Papers Calif. Acad. Sci.*, I, p. 183, 1890 (Amazons).

*Perugia* gen. nov. Eigenmann & Norris, *Revista Museu Paulista*, IV, p. 355, 1900.

*Luciopimelodus agassizii* Eigenmann, *Repts. Princeton Univ. Exped. Patagonia*, III, 1910, p. 383 (name only). Fisher, *Ann. Carnegie Mus.*, XI, 1917, p. 407 (Pará).

*Habitat*: Amazons.



PERUGIA XANTHUS (Eigenmann).

*Megalonema xanthum* Eigenmann, *Indiana University Studies*,

No. 16, p. 16, 1912.

*Habitat*: Girardot; Apulo.

MINUTES.





## MINUTES.

*Stated Meeting, January 3, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The decease was announced of

Charles Francis Himes, Ph.D., at Carlisle, Pa., on December 7, 1918, æt. 81.

Lewis S. Ware, at Paris, on December 20, 1918, æt. 67.

Mr. Leon Dominion, of New York, read a paper on "The Peoples of Central and Eastern Europe," which was discussed by Dr. Jastrow, Dr. Scott and Prof. Lingelbach.

The Judges of the Annual Election held this day between the hours of two and five in the afternoon reported that the following named members were elected according to the Laws, Regulations and Ordinances of the Society to be the Officers for the ensuing year.

### *President.*

William B. Scott.

### *Vice-Presidents.*

George Ellery Hale,  
Arthur A. Noyes,  
Hampton L. Carson.

### *Secretaries.*

I. Minis Hays,  
Arthur W. Goodspeed,  
Harry F. Keller,  
Bradley Moore Davis.

### *Curators.*

Charles L. Doolittle,  
William P. Wilson,  
Leslie W. Miller.



## MINUTES.

*Treasurer.*

Henry La Barre Jayne.

*Councillors.*

(To serve for three years.)

Mauricé Bloomfield,

John M. Clarke,

George H. Parker,

Arthur G. Webster.

*Stated Meeting, February 2, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The decease was announced of

Rossiter Worthington Raymond, Ph.D., LL.D., at New York,  
on December 31, 1918, æt. 78.

Theodore Roosevelt, LL.D., at Oyster Bay, on January 6, 1919,  
æt. 60.

Edward C. Pickering, LL.D., L.H.D., at Cambridge, on Feb-  
ruary 3, 1919, æt. 72.

The following papers were read:

"The League of Nations," by Russell Duane.

"Political Problems of Central and Southern Europe," by  
Charles D. Hazen of New York. (By title.)

"The Eastern Question," by Prof. Morris Jastrow, Jr.

"Organized Labor and Peace," by Prof. E. P. Cheyney.

*Stated Meeting, March 7, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The decease was announced of

George Carey Foster, F.R.S., D.Sc., at Herts, England, on Feb-  
ruary 9, 1919, æt. 83.

Hon. George Franklin Edmunds, at Pasadena, Calif., on Feb-  
ruary 27, 1919, æt. 91.

Charles L. Doolittle, Sc.D., LL.D., at Philadelphia, on March  
3, 1919, æt. 76.

Mr. Langdon Warner, introduced by the President, read a paper

on "Siberia and the Czechs," which was discussed by Mr. Goodwin and President Scott.

*Stated Meeting, April 4, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The following papers were read:

"Present Tendencies in the National Development of Waterways and Water Traffic, with Reminiscences of the Service rendered by the American Philosophical Society in behalf of early Canal Construction in America," by Wilfred H. Schoff. (Introduced by Dr. W. P. Wilson.)

"What Shall be Done with the Railroads?" by Emory R. Johnson, Sc.D.

*Stated General Meeting, April 24, 25, 26, 1919.*

*Thursday Afternoon, April 24, 1918.*

Opening Session, 2.30 o'clock.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

Dr. Alfred G. Mayor, a lately-elected member, having subscribed the Laws, was admitted into the Society.

The decease was announced of

Sir William Crookes, Kt., O.M., LL.D., D.Sc., at London, on April 4, 1919, æt. 87.

Henry Morse Stephens, B.A., M.A., Litt.D., at San Francisco, on April 16, 1919, æt. 61.

George Ferdinand Becker, Ph.D., at Washington, on April —, 1919, æt. 72.

The following papers were read:

"The Cosmic Force, Radio-Action," by Monroe B. Snyder, Director of the Philadelphia Observatory.

"The Conservation of Natural Monuments," by John M. Clarke, Ph.D., Sc.D., LL.D., Director of Department of Science and State Museum, Albany, N. Y.

"Detection of Ocean Currents by their Alkalinity," by Alfred G. Mayor, M.E., Sc.D., Director of Department of Marine



- Biology, Carnegie Institution of Washington, Princeton, N. J.
- "Some Oceanographical Results of the Canadian Arctic Expedition, 1913-1918," by Vilhjalmur Stefansson, A.B., Commander of Canadian Arctic Expedition. (Introduced by Mr. Henry G. Bryant.) (By title.)
- "Evolution and Mystery in the Discovery of America," by Edwin Swift Balch, A.B., of Philadelphia.
- "Benjamin Franklin's Art as Applied to Books for Elementary Teaching," by Charles R. Lanman, Ph.D., LL.D., Prof. of Sanskrit, Harvard University. (By title.)
- "The Energy Loss of Young Women during Light Household Muscular Activities," by Francis G. Benedict, Ph.D., Sc.D., Director of Nutrition Laboratory (Boston) of Carnegie Institution of Washington, and Alice Johnson.
- "The Relative Contribution of the Staple Commodities to the National Food Consumption," by Raymond Pearl, Ph.D., Professor of Biometrics, School of Hygiene and Public Health, Johns Hopkins University.
- "Hygiene and Sanitation as Improvised in the Zone of Operations during the Great War," by Bailey K. Ashford, M.D., Sc.D., Surgeon U. S. Army. (Introduced by Dr. W. W. Keen.) Discussed by Prof. Osborn.
- "Bloodless Removal of Foreign Bodies from the Lungs through the Mouth by Bronchoscopy," by Chevalier Jackson, M.D., Attending Laryngologist, Jefferson Medical College, Philadelphia. (Introduced by Dr. W. W. Keen.) Discussed by Dr. Keen.

*Friday, April 25, 1919.*

*Executive Session, 9.30 o'clock*

Proceedings of the Officers and Council was submitted.

*Morning Session, 10 o'clock.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The following papers were presented:

- "The New Discoveries of Extinct Animals in the West Indies and their Bearing on the Geological History of the Antilles,"

by William D. Matthew, A.M., Ph.D., Curator of American Museum of Natural History, N. Y. Discussed by President Scott.

"Characters and Restoration of the Sauropod Genus *Camarasaurus* Cope, from Type-Material in the Cope Collection of the American Museum of Natural History," by Henry Fairfield Osborn, Sc.D., LL.D., Research Professor of Zoölogy, Columbia University, and Charles C. Mook. Discussed by President Scott.

"Energy Conception of the Cause of Evolution," by Henry Fairfield Osborn, Sc.D., LL.D., Research Professor of Zoölogy, Columbia University.

"The Parasitic Aculeata, a Study in Evolution," by William M. Wheeler, Ph.D., Sc.D., Professor of Economic Entomology, Bussey Institution, Harvard University.

"Two Recent Entomological Problems—The Pink Bollworm and the European Corn Borer," by L. O. Howard, Ph.D., LL.D., Chief of Bureau of Entomology, U. S. Department of Agriculture, Washington.

HAMPTON L. CARSON, M.A., LL.D., Vice-President, in the Chair.

"Hydration and Growth," by D. T. MacDougal, Ph.D., LL.D., Director of the Department of Botanical Research, Carnegie Institution of Washington, Tucson, Arizona.

"Hydration of Colloids and Cell-Masses in Propionic Acid and its Amino-Compounds," by D. T. MacDougal, Ph.D., LL.D., Director of the Desert Laboratory, Tucson, Arizona, and H. A. Spoehr. (By title.)

"Sterility and Self-and-Cross-Incompatibility in Shepherd's Purse," by George H. Shull, Ph.D., Professor of Botany and Genetics, Princeton University.

"The Basis of Sex Inheritance in *Sphaerocarpos*," by Charles E. Allen, Ph.D., Professor of Botany, University of Wisconsin. (Introduced by Prof. Bradley M. Davis.)

"Hydrogen-ion Concentration of Nutrient Solutions in Relation to the Growth of Seed Plants," by Benjamin M. Duggar, A.M., Ph.D., Research Professor of Plant Physiology, Mis-



souri Botanical Garden, St. Louis. (Introduced by Prof. Bradley M. Davis.)

"The Relation of the Diet to Pellagra," by E. V. McCollum, Ph.D., Professor of Bio-Chemistry, Johns Hopkins University. (Introduced by Dr. Henry H. Donaldson.)

*Afternoon Session, 2 o'clock.*

GEORGE ELLERY HALE, Ph.D., Sc.D., LL.D., Vice-President, in the Chair.

The following papers were presented:

"The Eclipse Expedition from the Lick Observatory. Some Solar Eclipse Problems," by W. W. Campbell, Sc.D., LL.D., Director of the Lick Observatory, Mount Hamilton, Calif.

"The Expedition of the Mount Wilson Observatory to the Solar Eclipse of June 8, 1918," by J. A. Anderson, Ph.D., Mount Wilson Solar Observatory, Pasadena, Calif. (Introduced by Prof. John A. Miller.)

"The Lowell Observatory Eclipse Observations, June 8, 1918. Prominences and Coronal Arches," by Carl O. Lampland, A.M., Lowell Observatory, Flagstaff, Arizona. (Introduced by Prof. Eric Doolittle.)

"The Flash Spectrum," by Samuel Alfred Mitchell, Ph.D., Director McCormick Observatory, University of Virginia. (Introduced by Prof. John A. Miller.)

"Electric Photometry of the 1918 Eclipse," by Jacob Kunz, Ph.D., and Joel Stebbins, Ph.D., University of Illinois, Urbana, Ill. (Introduced by Prof. John A. Miller.)

"The Sproul Observatory Eclipse Expedition. The Form of the Coronal Streamers," by John A. Miller, A.M., Ph.D., Director of the Sproul Observatory, Swarthmore College, Pa.

"Results of Observations of the Eclipse by the Expedition from the Yerkes Observatory," by Edwin B. Frost, D.Sc., Professor of Astrophysics and Director of Yerkes Observatory, University of Chicago.

"Self-Luminous Night Haze," by E. E. Barnard, D.Sc., LL.D., Professor of Practical Astronomy, University of Chicago.

- "Photometric Measurements of Stars," by Joel Stebbins, Ph.D., Professor of Astronomy, University of Illinois. (Introduced by Prof. Henry Norris Russel.) (By title.)
- "Star Clusters and their Contribution to Knowledge of the Universe," by Harlow Shapley, Ph.D., Mt. Wilson Solar Observatory, Pasadena, Calif. (Introduced by Prof. George E. Hale.)
- "Tatar Material in Old Russian," by J. Dyneley Prince, Ph.D., Professor of Slavonic Language, Columbia University.

*Evening Session, 8.30 o'clock.*

Arthur Gordon Webster, Sc.D., LL.D., Professor of Physics, Clark University, Worcester, spoke on the "Recent Applications of Physics in Warfare."

*Saturday, April 26, 1919.*

*Executive Session, 9.30 o'clock.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

Certain proposed amendments to the Laws and Rules of Administration and Order and Resolutions in reference to amendments to the Charter, recommended by the Officers and Council were adopted.

Pending nominations for membership were read and the Society proceeded to an election. The tellers reported that the following nominees had been elected to membership:

*Residents of the United States:*

Robert Grant Aitken, Sc.D., Mount Hamilton, Cal.

Joseph Charles Arthur, Sc.D., Lafayette, Ind.

Edward W. Berry, Baltimore.

James Henry Breasted, A.M., Ph.D., Chicago.

Ulric Dahlgren, M.S., Princeton.

William Curtis Farabee, A.M., Ph.D., Philadelphia.

John Huston Finley, LL.D., Albany, N. Y.

Stephen Alfred Forbes, Ph.D., LL.D., Urbana, Ill.

Chevalier Jackson, M.D., Philadelphia.

Dayton C. Miller, A.M., D.Sc., Cleveland.

George D. Rosengarten, Ph.D., Philadelphia.



Albert Sauveur, S.B., Cambridge, Mass.

William Albert Setchell, A.M., Ph.D., Berkeley, Cal.

Julius O. Stieglitz, Ph.D., D.Sc., Chicago.

Ambrose Swasey, Sc.D., D.E., Cleveland.

*Morning Session, 10 o'clock.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

Prof. James Henry Breasted, a newly elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Artificial Formations Resembling Lunar Craters," by Captain Herbert E. Ives, B.S., Ph.D., of Philadelphia. Discussed by Prof. Magie, Mr. Davis and Prof. Webster.

"The Meteorological Service of the Signal Corps in the War," by Robert A. Millikan, Ph.D., Sc.D., Professor of Physics, University of Chicago.

"Detection of Submarines," by Harvey Cornelius Hayes, Ph.D., Naval Experimental Station, New London. (Introduced by Prof. John A. Miller.) Discussed by Prof. Webster.

"Errors Induced in Bullets by Defects in their Manufacture," by Ernest W. Brown, M.A., Sc.D., Professor of Mathematics, Yale University. Discussed by Messrs. Akimoff, Webster, Brush and Brown.

"Sound and Flash Ranging," by Augustus Trowbridge, A.M., Ph.D., Professor of Physics, Princeton University.

"The Work of the Ballistic Institute of Clark University," by A. G. Webster, Ph.D., Sc.D., LL.D., Professor of Physics, Clark University, Worcester, Mass.

"Alternating-Current Planevector Potentiometer Measurements at Telephonic Frequencies," by A. E. Kennelly, A.M., Sc.D., Director Research Division, Electrical Engineering Department, Massachusetts Institute of Technology, Cambridge, and Edy Velander. Discussed by Prof. Webster.

"The Genesis of Petroleum as Shown by its Nitrogen Constituents," by Charles F. Mabery, Sc.D., Emeritus Professor of Chemistry, Case School of Applied Science, Cleveland. (By title.)

- "Graphical Representations of Functions of the  $n$ th Degree," by Francis E. Nipher, Professor Emeritus of Physics, Washington University, St. Louis.
- "Glimpses of the Near East During the War," by A. V. W. Jackson, L.H.D., LL.D., Professor of Indo-Iranian Languages, Columbia University. (By title.)
- "The Empire of Amurru," by A. T. Clay, Ph.D., LL.D., Professor of Assyriology and Babylonian Literature, Yale University. (By title.)
- "The Science of Stealing (Steiyacastra) in Ancient India," by Maurice Bloomfield, Ph.D., LL.D., Professor of Sanskrit, Johns Hopkins University. (By title.)
- "The Crib of Christ," by Paul Haupt, Ph.D., LL.D., Professor of Semitic Languages, Johns Hopkins University.
- "The Atonement Idea Among the Ancient Semites," by Edward Chiera, Ph.D., Instructor in Assyriology, University of Pennsylvania. (Introduced by Prof. Morris Jastrow, Jr.)

*Afternoon Session, 2 o'clock.*

ARTHUR A. NOYES, Sc.D., LL.D., Vice-President, in the Chair.

*Symposium on Chemical Warfare.*

- "Historical Introduction," by Col. Marston T. Bogert, Ph.D., LL.D., Chemical Warfare Service, U. S. A.
- "Chemical Warfare and Research," by Col. George A. Burrell, Chemical Warfare Service, U. S. A. (Introduced by Col. Bogert.) (By title.)
- "Chemical Warfare and Manufacturing Development," by Col. Frank M. Dorsey, Chemical Warfare Service, U. S. A. (Introduced by Mr. A. A. Blair.)
- "Production of Chemical Warfare Munitions," by Col. William H. Walker, Chemical Warfare Service, U. S. A. (Introduced by Prof. H. F. Keller.)
- "Means of Defense Against Chemical Warfare," by Col. Bradley Dewey, Chemical Warfare Service, U. S. A. (Introduced by Dr. Philip B. Hawk.) Discussed by Prof. Webster, Dr. Keen and Mr. Rosengarten.



*Stated Meeting, May 2, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The President appointed Prof. J. C. Arthur to prepare an obituary notice of the late George Francis Atkinson.

The decease was announced of

Lucien Adam, at Rennes, France, on November 29, 1918, æt. 86.

Mr. Frederick Ives read a paper on "The Simplification of Photography," which was discussed by Prof. Miller and Mr. Davis.

*Stated Meeting, October 3, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

William Curtis Farabee, a newly elected member, subscribed the Laws and was admitted into the Society.

Letters accepting membership were received from

Robert Grant Aitken, Sc.D.,

Joseph Charles Arthur, Sc.D.,

Edward W. Berry,

James Henry Breasted, A.M., Ph.D.,

Ulric Dahlgren, M.S.,

William Curtis Farabee,

John Huston Finley, LL.D.,

Stephen Alfred Forbes, Ph.D., LL.D.,

Chevalier Jackson, M.D.,

Dayton C. Miller, A.M., Sc.D.,

George D. Rosengarten, Ph.D.,

Albert Sauveur, S.B.,

William Albert Setchell, A.M., Ph.D.,

Julius O. Stieglitz, Ph.D., Sc.D.,

Ambrose Swasey, Sc.D., D.E.

A letter was read from Mr. Thomas A. Edison, resigning membership.

The decease was announced of the following members: .

Francis B. Gummere, A.B., Ph.D., LL.D., Litt.D., at Haverford on May 30, 1919, æt. 64.

William Gilson Farlow, A.M., M.D., at Cambridge, on June 3, 1919, æt. 74.

Sir Boverton Redwood, F.R.S., at London, on June 4, 1919,  
æet. 73.

Ira Franklin Mansfield, at Beaver, Pa., on June 7, 1919, æet. 77.

Rt. Hon. John William Strutt, Lord Rayleigh, O.M., LL.D.,  
D.C.I., on July 1, 1919, æet. 77.

Gustavus Retzius, M.D., at Stockholm, on July 21, 1919, æet. 77.

Charles Conrad Abbott, M.D., at Bristol, Pa., on July 27, 1919,  
æet. 76.

Ernest Haeckel, Ph.D., at Jena, on August 8, 1919, æet. 85.

Andrew Carnegie, LL.D., at Lenox, Mass., on August 11, 1919,  
æet. 84.

The following papers were read:

"Trogloglanis Pattersoni, a New Blind Fish from San Antonio, Texas," by Carl Eigenmann, Ph.D.

"On the Luciopimelodinæ, a New Subfamily of the South American Siluridæ," by Charles S. Driver (communicated by Dr. Eigenmann).

*Stated Meeting, November 7, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

Mr. George D. Rosengarten, a newly elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"An International Treaty which Resulted in a Scientific League of Nations," by Hon. William C. Redfield.

"The Metric System of Weights and Measures," by Dr. Samuel W. Stratton.

"Child Maintenance at Public Expense," by Elisha Kent Kane.

"Tectonics of Laccolithic Mountains," by Charles Keyes (communicated by Prof. W. B. Scott).

*Stated Meeting, December 5, 1919.*

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The decease was announced of

Charles Henry Hitchcock, A.M., Ph.D., LL.D., at Honolulu,  
on November 6, 1919, æet. 83.



Julius F. Sachse, Litt.D., at Philadelphia, on November 4, 1919, æt. 76.

The following papers were read:

"The Deep Kansan Pondings in Pennsylvania and the Deposits Therein," by Prof. Edward H. Williams, Jr., which was discussed by President Scott.

"The Parallaxes of Fifty Stars, determined at Sproul Observatory," by John A. Miller (by title).

"The Experiences of a Sanitary Officer in the Army," by Dr. Alexander C. Abbott, which was discussed by Mr. Field, Dr. Jastrow, and President Scott.

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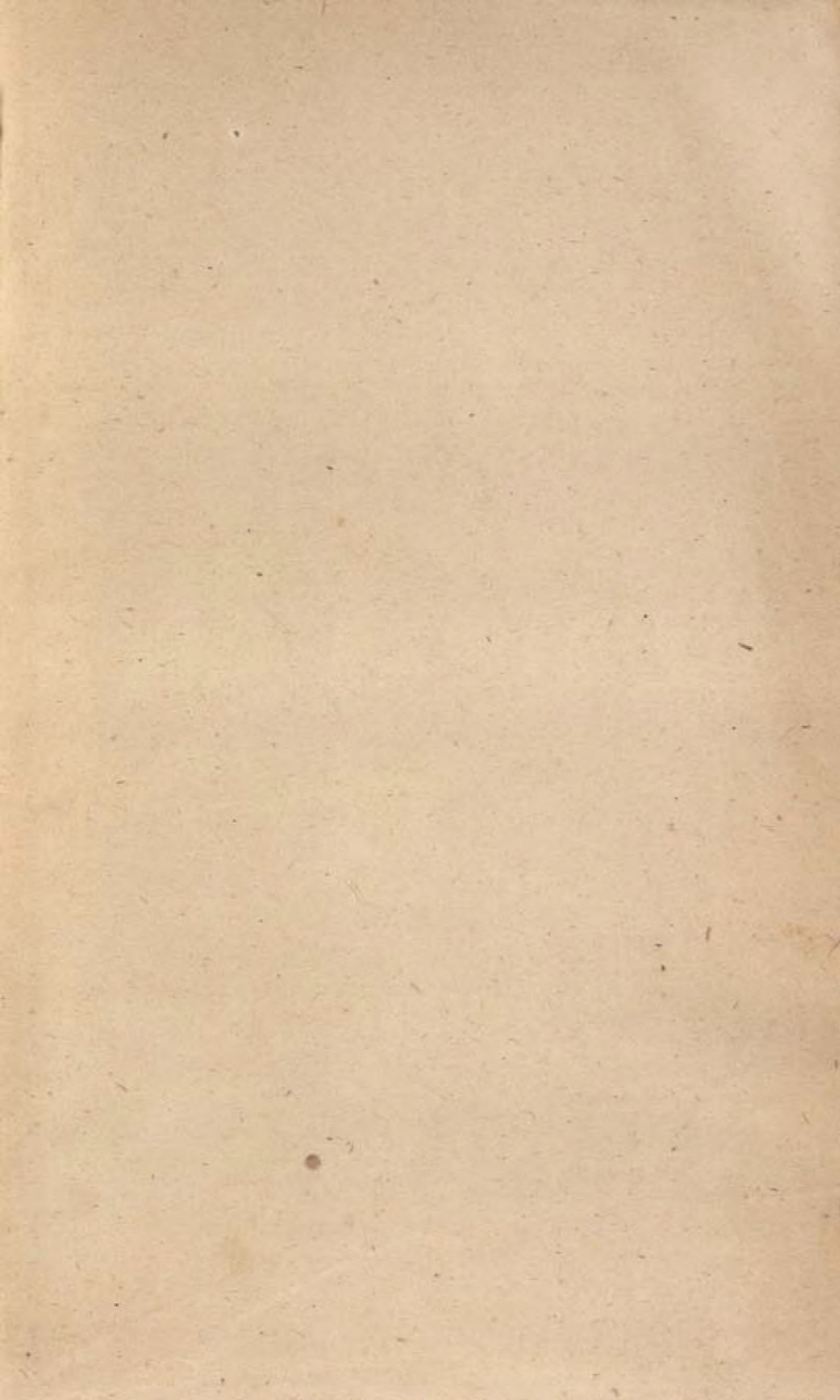
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N.C.

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